REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1954

COMMONWEALTH AGRICULTURAL BUREAUX
1 JUL 1955

Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1954

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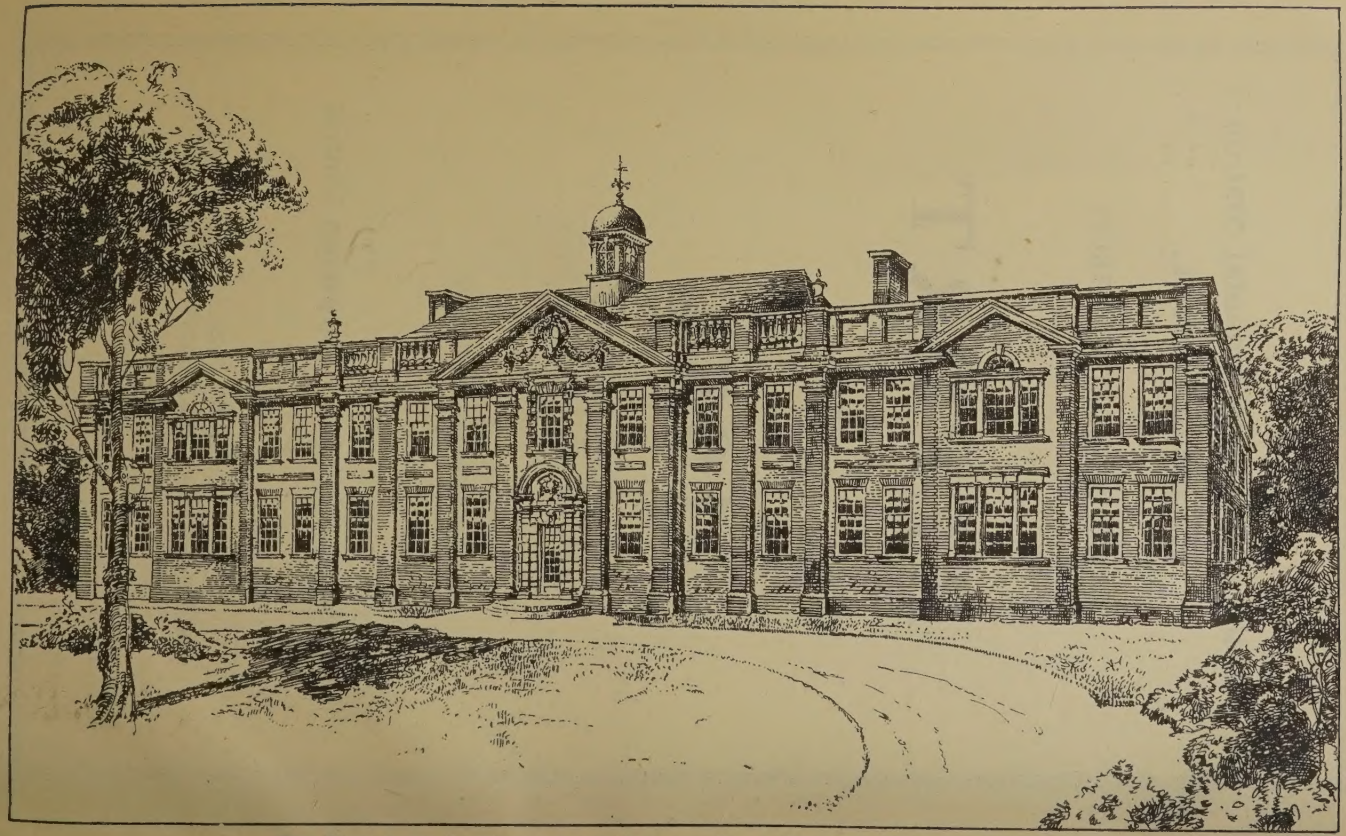

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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J. R. Moffatt, B.Sc.(Agric.)(Lond.), N.D.A., A.I.B.A.E.

Assistant

G. F. Cole

Bailiff

A. W. Neill

Farm Workers

C. Hathaway, Clara E. Horn, W. Hummerston, W. A. McCallum, K. Wilson, W. Wilson.

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director

F. G. Gregory, D.Sc.(Lond.), F.R.S.

Head of Department

F. J. Richards, D.Sc.(Birm.), F.R.S.

Scientific Staff

E. H. Grice-Hutchinson, B.Sc.(St. And.)
C. A. Priestley, B.A.(Cantab.)
A. R. Rees, B.Sc.(Wales)
W. W. Schwabe, Ph.D.(Lond.)

Assistant Staff

W. S. Biggs, Mrs. Maureen Rees, C. Sinclair, Pamela Smith.

The Commonwealth Bureau of Soil Science

Director	G. V. Jacks, M.A.
Consultant Director ...	Sir W. G. Ogg, M.A., Ph.D., LL.D.
Assistant Director ...	W. D. Brind, B.Sc.
Assistants	Kathleen H. Carver, B.Sc. Mrs. M. Kathleen Milne, B.Sc. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Senior Clerk	Cynthia M. Horn
Clerks	Marguerita D. Payne, Iris Simpson, Mrs. Rita M. Starkins

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly sixty years. Lawes died in 1900, and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943, when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir. J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income from which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department. In 1946 Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research Department.

In 1947 the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted, and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

In 1940 the south wing was completed and the old chemical laboratories reconstructed. These extensions and reconstructions provide accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition, a range of pot-culture

houses was built. In 1939 a laboratory was completed for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power; further additions were made in 1939–40. A range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but Rothamsted also gains considerably by this closer association with the universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934 the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted estate were completed. The Lawes Agricultural Trust now owns the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers and from oversea sources.

During 1951–52 the Manor House was converted into a Hall of Residence, providing accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas. An illustrated guide to the Manor with an account of its history has been published (1953) under the title *The Manor of Rothamsted*.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually reaching out to many parts of the world. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

Rothamsted offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and societies, was rapid, until it now contains :

	(Approximately)
Periodicals ... ... (Current, 1,600)	4,700
Books, 1841–	10,000
Books, 1471–1840 ... ... (including 14 incunabula)	3,500
Bound volumes of pamphlets	400
MSS.	100
Maps	300
Prints	100

—in all about 18,000 items, comprising some 50,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most-used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471–1840), which is kept separate from the rest, includes fourteen incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture —produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry*, by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948, when Lord Northbrook presented to Rothamsted his father's collection of prints.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books on agriculture (Rothamsted, 1926; second edition, 1940; supplement 1949). A complete catalogue of the serial publications in the Library was published in 1954.

INTRODUCTION

By The Director

Rothamsted suffered a great loss in the death of Dr. E. M. Crowther on 17 March 1954 at the early age of fifty-six. He joined the staff in 1917, and ten years later, when he was only thirty, was appointed Head of the Chemistry Department, a position he occupied until his death. In 1950 he became one of the two Deputy Directors of the Station. Accounts of Dr. Crowther's career and of his outstanding contributions to agricultural science, and particularly soil science, have appeared elsewhere; a list of his published papers is included in this report. His whole professional life was devoted to Rothamsted, and his influence on the policy and research work of the Station was profound. He is greatly missed for his scientific leadership and equally as a friend for whom we all had the greatest affection.

Professor A. C. Chibnall, a member of the Lawes Agricultural Trust Committee since 1943, and Sir E. B. Bailey, a member since 1944, both representing the Royal Society, retired from the Committee in November 1954, and were succeeded by Professor A. Robertson and Professor V. B. Wigglesworth. In succession to Dr. E. M. Crowther, Dr. R. K. Schofield was appointed to the Headship of the Chemistry Department, and Dr. H. L. Penman succeeded Dr. R. K. Schofield as Head of the Physics Department from October, 1954. Dr. P. H. Gregory, who joined the Plant Pathology Department as Mycologist in 1948, left at the end of January 1954 to become Professor of Botany at the Imperial College of Science and Technology, London. At the request of the Colonial Office, Dr. A. Muir visited Nigeria to advise on the Nigerian Soil Survey. He attended the 2nd Inter-African Soils Conference and the 5th International Congress of Soil Science in the Belgian Congo, and visited Northern Rhodesia, Nyasaland and the East African Colonial Territories. Dr. H. Greene led the United Kingdom delegation at the Inter-African Soils Conference and attended the 5th International Congress of Soil Science in Leopoldville. He also made a tour of Colonial Territories in West, Central and East Africa, and visited Aden and British Somaliland. Dr. C. B. Williams spent two months at the West African Cacao Research Institute at Tafo, Gold Coast, to advise on insect pests of cocoa; Dr. F. Raw has been seconded to the Institute to investigate the damage done to cocoa by capsids, and Miss Margaret Holden to work on problems connected with swollen shoot disease of cocoa. Dr. A. W. Taylor has been awarded a post-doctorate fellowship at the University of Wisconsin, Madison, and Dr. D. M. C. MacEwan has been given two years' leave of absence to work in the Faculty of Sciences in the University of Granada. To get a wider knowledge of the biology of forest soils, Dr. P. W. Murphy is spending a year with Professor Kühnelt in the Zoology Department of the University of Vienna. Mr. C. A. H. Hodge has been seconded from the Soil Survey to the Government of Aden for several months, and Mr. L. F.

Curtis to Hunting Aerosurveys for six months' work in Iraq. Mr. G. E. Hodnett spent four weeks visiting agricultural and statistical departments in the West Indies. Other members who spent shorter periods abroad to learn special techniques were Dr. J. M. Bremner, who worked for three months with Professor W. Flaig, Director of the Institute of Soil Biochemistry, Braunschweig-Völkenrode, and Dr. B. Kassanis, who studied tissue culture techniques with Dr. Morel at the Station de Physiologie Végétal, Versailles.

Sir William Ogg was one of a party of five agriculturists from the United Kingdom who attended on behalf of the Ministry of Agriculture the All-Union Agricultural Exhibition of the U.S.S.R. in Moscow in August, at the invitation of the Soviet Ministry of Agriculture. He also paid a brief visit to the Dokuchaev Soil Institute.

Representatives from Rothamsted attended the International Congress of Geodesy in Rome, the 15th International Beekeeping Congress and International Conference of Bee Research workers in Copenhagen, the International Union of Crystallography and Supplementary Meeting on Clay Minerals in Paris, the International Botanical Congress in Paris, the International Photobiological Conference in Amsterdam, the Conference of the International Union for the Protection of Nature in Copenhagen, meetings of the International Institute of Sugar Beet Research in Belgium and Eire, and the Virus Yellows Colloquium at Bergen-op-Zoom.

Mr. F. C. Bawden accepted the invitation of the Indian Science Congress Association to attend the Science Congress at Hyderabad in January, and afterwards visited Indian Universities and agricultural research stations. Dr. H. G. Thornton a member of the UNESCO Advisory Committee on Arid Zone Research, visited India in October to attend a meeting of the Committee in New Delhi, followed by a Symposium on Solar Energy and Wind Power organized by UNESCO and the Indian Government; Mr. N. W. Pirie also attended the Symposium. Dr. D. A. Osmond attended a meeting at Ghent of a sub-group set up under F.A.O. to study soil classification and survey in Europe. Dr. G. W. Cooke was invited to spend six weeks at the Headquarters of F.A.O. in Rome, to prepare their "Annual Review of world production and consumption of fertilizers"; he also attended the General Assembly of the International Centre of Chemical Fertilizers in Zurich.

Dr. C. B. Williams was elected a Fellow of the Royal Society. Sir William Ogg was elected President of the Society of Chemical Industry for a second year from July 1954.

Visitors

Over three thousand visitors from many countries came to Rothamsted in 1954. H.R.H. the Duke of Edinburgh paid an informal visit on 20 July, spending the morning on the experimental farm and the afternoon in the laboratories. Other visitors included Vice-Admiral Sir Peveril William-Powlett, the Governor, and Mr. Garfield Todd, the Prime Minister, of Southern Rhodesia; The Hon. R. C. Wilson, C.M.G., a member of the Legislative Council of New South Wales; Sir Charles Jeffries, K.C.M.G., O.B.E., Deputy Under-Secretary-of-State for the Colonies; Sir Alan Hitchman, K.C.B.,

Permanent Secretary to the Ministry of Agriculture and Fisheries; Mr. Milan Ivanovic, Yugoslav State Counsellor of Agriculture; a party of senior Danish officials, including the Permanent Secretary to the Ministry of Agriculture; and many scientists from overseas. Amongst parties visiting Rothamsted were members of the Parliamentary and Scientific Committee, the Comparative Medicine Section of the Royal Society of Medicine, the 5th Commonwealth Mycological Conference, a French Technical Mission, the 6th Commonwealth Entomological Conference, and the Jubilee Conference of the Association of Applied Biologists.

Buildings

During the year the new temporary building for the Statistics Department has been completed. This houses the electronic computer and provides a much-needed conference room and additional accommodation for staff and temporary workers. The buildings for fertilizer work and for experiments on the production of leaf protein have also been in use since the early summer. The new Plant Pathology building is nearing completion.

The Work of the Station

Several lines of fundamental research in the **Physics** Department are proving useful or showing promise. During the year, H.M. Stationery Office has published for the Ministry of Agriculture a Technical Bulletin on the calculation of irrigation need in England and Wales, which, with valuable help from others, is mainly a joint effort of the Physics Department and the Agricultural Branch of the Meteorological Office. This estimate of need is purely meteorological, but as agricultural interest quickens, more field experiments will show how far the meteorological data supply a farming need. An experiment at Woburn has already shown that irrigation of grass and early potatoes is very much worth while. Intensification of production has been accompanied by an increase in diseases and pests, and in recent years attention has been given to the micro-environment of the growing crop; there has been a steady development of techniques for measuring the "weather" experienced by plant pathogens and insect pests. This involves collaborative work with the biologist, and recent work on the potato crop has given a broad picture of the conditions that might affect the activity of aphid vectors for virus diseases, and those that control infection and spread of potato blight. In parallel with these studies of the aerial environment of the plant, progress has been made on the soil environment. It is always assumed that good soil structure is an essential condition for successful farming, but research has been hindered by lack of a suitable way of expressing structure quantitatively; a new sodium saturation method for determining the stability of moist soil crumbs is proving useful, both in field and laboratory tests. There are indications that grass leys are more efficient than lucerne in improving soil structure, and it has been shown that certain synthetic soil conditioners are much more efficient in stabilization of acid soil than of soil containing free calcium carbonate, a result in accord with previous field experience. In addition to

promising work on the mechanism of crumb formation, further progress has been made in the development of techniques for estimating the potash and phosphate status of soils.

In the **Chemistry** Department further work has been done on the agricultural value of phosphate fertilizers insoluble in water, and data have been obtained on solubility properties which will be of value in laboratory testing and in specifying the soil conditions which influence the effectiveness of the different calcium phosphates present in fertilizers. The radiotracer work on the uptake of phosphorus by plants has been continued and field experiments carried out for the third year to compare nitrophosphate with superphosphate plus equivalent nitrogen. Applied to cereals, the nitrophosphates tested gave poorer crops, but the difference was much less marked if they were drilled with the seed. Fertilizer placement experiments on horticultural crops showed marked benefits from placing fertilizers at the side of the seed for cabbage, lettuce, onions, maize, broad beans and runner beans, as regards both yield and earliness for market. Placing was twice as efficient as broadcasting for lettuce and cabbage; for beans, broadcast fertilizer was of little use. The increased returns may well be sufficient to justify the purchase of special placement drills for these high-value crops. In experiments with potatoes it was found that on the average 1 cwt. of nitrogen was sufficient for maximum yield, and there was no gain from splitting the nitrogen dressing and applying part at planting and part at " earthing-up ". It was often assumed that much of the benefit of placement was due to localizing the phosphate near to the seed and that for the more mobile nutrients, nitrogen and potash, broadcasting was satisfactory. The results of recent work, however, have modified this view, and it appears that for some crops, including potatoes, both nitrogen and potash are more efficient when placed close to the seed. Useful progress has been made in the improvement of laboratory techniques for determining ammonium and nitrate in soil and for studying the release of nitrogen and phosphorus in soil organic matter. In view of the fact that British farmers spend about £20 million annually on nitrogen fertilizers, these lines of work are highly important.

In several old forest nurseries " partial sterilization " of the soil by formalin and chlorpicrin has given consistently good results over a number of years, if applied during the winter before sowing. As soil treatments are difficult to apply during the winter months, summer and autumn applications were tested during a fallow period. The summer application of chlorpicrin and the autumn application of both materials gave promising results.

The **Pedology** Department continues to give much attention to processes of soil formation and to the minerals occurring in soils and soil clays. This work is very closely linked up with soil surveys, both in this country and in Colonial Territories. In a soil survey in Nyasaland, a study of the mineralogy has thrown light on the origin of the parent materials of the soils and confirmed the principles on which they have been classified. Additional work has been done on the gilgai soils of Kenya. Progress has been made with the study of clay minerals of soils and drifts, and particular attention has been given to the Clay-with-flints. The properties of clay minerals are being investigated, and new instruments for this

purpose have been designed. In the spectrographic section, improved methods are being introduced which will enable the analyses to be done much more quickly and accurately. The study of the minor elements in the Lias clay and in numerous soils from Wales has been continued as part of the programme for determining their general distribution in the soils of Britain. Further studies have been made of the effects of materials washed out of leaves on soil constituents and on soil formation.

In the **Soil Microbiology** Department the possibility of using antagonistic micro-organisms to control root disease fungi in the soil is being explored. Various soil organisms, particularly certain actinomycetes, are a source of antibiotics used in medicine, but there has been very little evidence that antibiotics are actually produced in the soil and are active in it. Many actinomycetes are able to attack root disease fungi, but there has been doubt as to whether their antagonistic action in soil was due to competition for some essential nutrient or to antibiotic secretions. Evidence has now been obtained that it is an antibiotic action. It has been shown, first, that actinomycetes antagonistic to the root fungus *Helminthosporium* inhibit the germination of the spores of this fungus in soil and produce symptoms of toxic action on the germinating hyphae; secondly, that these symptoms are characteristic for the different actinomycete species tested and are exactly similar for each species to the symptoms shown in agar culture; thirdly, that the pure antibiotic " Actinomycin " produces the same symptoms on germinating spores in soil as are produced by *Streptomyces antibioticus*, which produces this antibiotic.

Further work has been done on the strains of clover nodule bacteria which either fail to produce nodules or produce nodules that are ineffective in fixing nitrogen. It has previously been found that on acid soils an effective strain often produced ineffective variant forms. Recent experiments have shown, however, that acidity is not the only factor. Different strains of bacteria differ greatly in their tendency to produce these ineffective variants, and attempts are being made to select genetically stable strains for use in seed inoculation. The investigation of the virus that destroys clover nodule bacteria is being continued, and a study made of the adaptability of free-living nitrogen-fixing bacteria to different levels of soil acidity and calcium content. Further work has been carried out on the decomposition of certain weed-killers and insecticides by soil micro-organisms, and in co-operation with the Bee Department attempts are being made to isolate and grow the organism which causes European Foul Brood.

In the **Botany** Department the work on plant nutrition has included studies of nutrient uptake and interaction between iron and other micronutrient elements. It has been shown that the disease known as " cloud " or " blotchy ripening ", which seriously affects the quality of tomato fruits, is not due, as had previously seemed possible, to manganese toxicity. The " cloud " symptoms were induced when plants at a late stage of growth were transferred to a more dilute culture solution. In further experiments on nutrient uptake from spraying foliage it was shown that absorption of phosphorus through the leaves of swede plants may reduce uptake through the roots by a corresponding amount. This happens, how-

ever, only when the supply of phosphorus to the roots is high relative to other nutrients, and not when there is a balanced supply of nitrogen, phosphorus and potash. Weed studies have been continued, with special attention to wild oats. Experiments comparing the effects of different winter- or spring-sown cereals on the establishment and growth of wild oats and other weeds have emphasized the importance of crop competition in limiting weed infestation. Other lines of work in the department include studies of the physiological effects on plants of virus infection and of the physiological limitations of crop yield. A field experiment on kale showed that there is an optimal leaf area, per unit area of land, for dry matter production. When this is exceeded, in a heavy crop, the rate of dry matter production is then reduced, because the leaves interfere with each other and their average photosynthetic efficiency is decreased, presumably by mutual shading.

Most biological processes depend on the action of enzymes, and the **Biochemistry** Department continues to devote most attention to the detailed study of some representative enzyme systems. Work on the ribonucleases has been carried as far as it is intended to take it at present, and is now being published. The study of various oxidizing systems continues, both because they are widely distributed in nature and because a better understanding of them is likely to help in interpreting the effects of trace metal deficiencies. Although a knowledge of enzymic differences between bracken and crop plants will obviously not necessarily lead to a method for eradicating bracken, this knowledge will probably help. A comparative survey of the enzymes has therefore been begun.

All work on enzymes involves the study and purification of proteins, and highly-purified preparations of peroxidase and ribonuclease have been made. The properties of purified virus preparations have also been investigated. This work is done with very small quantities of material. At the other extreme, progress has been made in the extraction of protein from leaves in bulk. With a pulper and press designed for this purpose, fresh greenstuff can be processed at the rate of 1 ton per hour and one-third or more of the protein extracted. The best methods for making dry protein from this in a form suitable for feeding to non-ruminants, including man, are now being studied. Until this has been done it is not possible to judge whether this method of getting food from a crop is economic. It is, however, already clear that with the new continuous press it is possible to remove much of the water from grass, and this may lead to economies in commercial grass drying.

Two other lines of work deserve mention. The first is on the effect of variations in illumination on the concentration of organic acids in the leaf. This is being done in the hope that it may provide an explanation of the effect that such variations have on the susceptibility of the leaf to virus infection. The second is a study of the chemical nature of those components of fungal mycelia that are resistant to attack both by enzyme preparations and mixed soil organisms. Such material may be expected to accumulate as part of the soil organic matter.

In the **Plant Pathology** Department much new information was obtained about the conditions that favour infection and virus

multiplication in leaves newly inoculated with viruses. Virus particles seem to be continually synthesized and broken down in infected cells, and the ratio of breakdown to synthesis is increased by increasing temperature. Many experiments were made with the insect-transmitted viruses that affect cruciferous crops; the incidence of the aphid-transmitted cauliflower mosaic was decreased by surrounding seedbeds with rows of barley; of two flea-beetle transmitted viruses found damaging field crops, one was related to turnip yellow mosaic virus, but the other seems distinct from any previously recognized and is provisionally called turnip crinkle virus. *Beta maritima* tolerated infection with strains of sugar beet yellows virus better than did *B. vulgaris*, but varieties of sugar beet also differed greatly in their response to infection; usually, but not always, the yield of roots was correlated with the severity of leaf symptoms. Normal-looking plants of many potato varieties were found to contain a virus serologically related to carnation latent virus; the virus in potatoes was not transmitted by aphids that transmit the one from carnation, and the two infect different kinds of plants.

In conjunction with the Insecticides Department experiments were done on the spraying of potato crops with persistent insecticides. This prevented the spread of leaf roll and decreased the spread of severe mosaic between plants within a crop, but did not prevent these diseases being introduced into healthy crops. The incidence of yellows in beet, both stecklings and the root crop, was decreased by spraying with systemic insecticides; although yellows was not prevalent early in the season, spraying considerably increased yields in some root crops.

Potato blight was exceptionally damaging at Rothamsted in 1954 because the crop grew slowly and only one-third of the potential yield of tubers was formed when the disease became prevalent; fungicidal sprays increased the yield by 2·4 tons/acre, whereas in 1953, when blight was prevalent at the same time, they gave an increase of only 0·5 tons. In experimental plots in which infected tubers were planted, blight first appeared on 28 May, and there were six "generations" or "spreads" of infection before the fungus became plentiful enough to cause general infection about the end of July. The wet summer made eyespot unusually prevalent in all the wheat experiments, and further evidence was obtained that the optimum seed rate depends on whether or not the land is infected with this and take-all fungus. On contaminated land a seed rate of $1\frac{1}{2}$ bushels of the variety Squarehead's Master gave higher yields than 3 bushels, but not on clean land. The optimal seed rate, however, varied with the different wheat varieties. The effect of seed rate on lodging in spring-sown Proctor barley was tested at three levels of nitrogen; lodging was particularly severe with high seed rate and heavy nitrogen dressings. In this experiment, increasing the seed rate from 1 to 3 bushels and ammonium sulphate from $1\frac{1}{2}$ to 3 cwt. increased the rate at which the crops lodged without increasing the yield of dressed grain. Further work on cereal mildews showed that their incidence was increased by late sowing and by nitrogenous fertilizers; the yield of Plumage Archer barley, a susceptible variety, was increased by amounts up to one-third by spraying with fungicides; spraying a resistant variety (Haisa II) gave no increase. In an investigation on pea diseases, a range of

Fusaria was isolated, which together and separately cause three diseases. *F. oxysporum* causes wilt, *F. solani* root rot, and the two together " St. John's Disease ", which is less severe than the other two and previously recognized only in continental Europe. Cultures of *F. oxysporum* pathogenic to the seedlings of Sitka spruce were isolated from diseased plants in forest nurseries, and this may contribute to the difficulties in raising healthy plants in old nurseries.

Further work carried out with fungicides to control seedling diseases of sugar beet gave evidence of the benefits derived from soaking the seed in solutions of ethyl mercury phosphate. In the Docking district of Norfolk and certain other places with light, alkaline soils, sugar beet are often subject to what has been termed " Docking Disorder ". Two fungi, *Pythium* and *Rhizoctonia*, have been isolated from affected plants, but they seem to be insufficiently virulent to be the chief cause of the trouble. Work has been continued on *Botrytis cinerea*, which is the main cause of rots in stored sugar beet and in clamped fodder beet and mangolds.

The **Nematology** Department is giving much attention to the study of eelworm populations and conditions under which they build up. In an experiment on cereal root eelworm at Stoke-on-Tern (Salop), an estimate is being made of their annual rate of multiplication in soil cropped with cereals, both winter and spring sown, with and without fertilizers. At another centre, the eelworm population increased under barley and dropped under linseed and cocksfoot. Observations are also being made of eelworm numbers on some of the old experimental fields at Rothamsted. For instance, beet eelworm on Barnfield has been surveyed for the third time. In spite of the host crops (mangolds and sugar beet) being grown every year, the eelworm population has remained about the same since 1946, and broadly speaking the parasite is most prevalent on the plots where the manurial treatments give the highest yields. The cereal root eelworm has been found in low numbers on Broadbalk (continuous wheat) and Hoosfield (continuous barley), and detailed surveys are being undertaken.

Pot experiments have been carried out with tobacco, potatoes and brussels sprouts to ascertain the effect of different levels of eelworm population on the height and weight of the plants. In general, it was found that the stunting due to the parasite was proportional to the logarithm of the number of eelworms added. A very low infestation, however, gave slightly taller and heavier plants than the uninfested control pots. This effect can perhaps be ascribed to mild root pruning by the parasite.

Work has been continued on the relationship between eelworms and their host plants, including the resistance of varieties of cereals to eelworm attack. Further investigations have been made of the root diffusates which lead to hatching of cysts, and experiments started on the physiology of the potato root eelworm. Previous work had indicated that soil fumigation failed to kill eelworms near the surface, and it has been shown that this can be dealt with by drenching the surface with solubilized cresol immediately after injecting the fumigant. Such double treatments may be practicable in glasshouses.

In the **Insecticides** Department much attention is being given by the biochemists to the way in which the very poisonous organo-

phosphorus insecticides act. It is generally assumed that they prevent certain necessary enzymes (the esterases) from functioning. This action on these enzymes in plants and insects is being studied, particularly the different effects they have on the enzymes of different species of insects. This is being done from the egg stage onwards, and the knowledge obtained may help in the search for organophosphorus compounds more poisonous to insects and less toxic to man. The biologists have spent most of their time on problems directly concerned with chemical control of pests of agricultural crops. A number of aspects of the control of black aphis (*Aphis fabae*) on field beans have been studied, and it has again been shown that considerable increases in yield can be obtained with a single early application of an insecticide. In the investigations on the control of wheat bulb fly (*Leptohylemyia coarctata*) progress has been made in laboratory rearing techniques which are essential for the study of its biology and control. Small-scale field experiments have indicated that effective control of larvae attacking the wheat plant may be obtained both with an insecticide in the soil and one applied later to the growing plant. These results require to be confirmed and amplified. Assistance has been given to the Home Grown Threshed Peas Joint Committee in a study of the chemical control of pea weevil (*Sitona lineatus*), and it has been shown that a systemic insecticide may be helpful though not a complete answer to the problem.

In the **Entomology** Department the work on insect migration and the effect of weather conditions on insects has been continued. Further work has been done on gall midges of economic importance, including a study of the biology of the Hessian fly and especially its host range. In view of the interest in clover seed production, investigations have been re-started on gall midges of clover, and it has been found that there is a widespread infestation of white clover by several species of midges, one of which is probably the well-known red clover seed midge. The midges of various grasses and lucerne are also being studied.

Much attention continues to be given to aphids, particularly to the way in which they spread and to their natural enemies. In the wheat bulb fly experiments, several new hosts have been found amongst the grasses, and the soil conditions favourable to egg laying are being studied. It has been suggested that soil organisms, especially earthworms, may play a considerable part during the rehabilitation of poor grassland, and, in co-operation with the Soil Survey, experiments have been laid down on two hill farms in Lancashire. In co-operation with the Nature Conservancy observations are being made on the effect of weed killers on insect populations.

The **Bee** Department continues to give attention to foraging behaviour, swarming and the social organization in the hive. It has been shown that foraging activities can be set going by the liberation in the hive atmosphere of a scent which the bees have already learned to associate with some source of food. This observation may help to explain some of the problems encountered when attempts have been made to direct bees to particular crops for purposes of pollination. There are also indications that flowers in which the nectar concentration is on the increase are particularly attractive to

bees. Further work has been done on the nature and functions of " queen substance ", which the bees of a colony seek by licking the body of their queen. It has been demonstrated biologically that this substance is present in the honey-stomachs of worker bees who have recently been in contact with a queen. It would appear that it controls not only the production of further queens but also the development of the ovaries of worker bees. By means of radio-active tracer technique additional information has been obtained on the extent to which the bees of a colony share the sugary liquids collected by the foraging members. Progress has been made with the work on bee diseases, including Nosema, Acarine disease and European Foul Brood. Various acaricides for the treatment of Acarine disease were tested, and one was found which killed all the life stages of the mite responsible for the disease without harming the bees. Work on queen introduction, bee-breeding, and the biology and behaviour of bumble bees has been continued.

In the **Statistics** Department much time has been devoted to investigating the possibilities of the recently installed electronic computer and adapting it to our needs. It has proved reasonably reliable, and has already done some useful work. It is often thought that the main feature of these machines is their speed, but equally important is their ability to perform long and complicated trains of operations without the intervention of the human operator. The introduction of electronic methods of computation will make available for regular use statistical methods which at present are scarcely used because of the heavy numerical work involved, and it will also facilitate and speed up many of the routine analyses which are at present done on desk machines. Progress has been made on various agricultural surveys. The Survey of hill and livestock rearing farms, which has just been completed, provides information on the returns being obtained from public and private expenditure, and will indicate what scope there is for further expenditure on upland farms. The Survey of fertilizer practice has been extended to twelve more districts, and a further Survey of rabbit damage has been carried out. Collaboration on the Survey of diseases of dairy cattle has been continued and assistance provided in various other livestock surveys. A good deal of work has been done on the re-organization of the long-term and classical experiments at Rothamsted and Woburn, and there has been the usual volume of routine work on the design and analysis of field and laboratory experiments for Rothamsted and other research stations and for the National Agricultural Advisory Service. Work for the Colonial Office has been continued, and a training course in sampling theory and practice, mainly for officers in the Colonial Service, which was organized jointly with the Division of Research Techniques of the London School of Economics, was held at Rothamsted.

The extensive programme of **Field Experiments** at Rothamsted and Woburn was carried out successfully in spite of very unfavourable weather conditions, and some 2,700 plots and over 500 micro-plots were handled by the experimental staff. A matter of great importance for the classical experiments was the mapping of the soils for calcium carbonate and pH. As a result of the situation revealed by this survey, liming schemes for Broadbalk, Hoosfield, Agdell and the Exhaustion Land were approved by the Lawes

Agricultural Trust Committee and have now been carried out. The acid areas had arisen from two causes: first, irregularity in the original application of chalk and, secondly, losses of calcium carbonate due to repeated dressings of ammonium sulphate and, to a lesser extent, rape cake. The schemes are designed to correct the first of these by a single chalk dressing and the second by a compensating application of chalk with the above manures. The four-course rotation, testing residual effects of organic manures and phosphatic fertilizers, has now been completed, and the results obtained since the experiment was started in 1930 have been summarized. The first complete set of test crops on the ley–arable rotation experiment, started in 1949, has been harvested, and interesting differences are already emerging. Most of the annual and short-term experiments are discussed in the reports of the various departments.

At Woburn, the declining level of yield on the classical wheat and barley plots is probably due mainly to increasing soil acidity and weed competition, but there may be other factors. A liming programme has now been drawn up which should greatly increase the value of these experiments, and enable the effect of liming on weeds to be studied. The irrigation experiment, testing controlled watering of agricultural crops, encountered a wet summer, in which even the cocksfoot ley showed little or no benefit from irrigation. Watering, however, doubled the percentage of self-sown *Poa annua* in the ley. The poor summer enabled the behaviour of exotic crops under very unfavourable conditions to be studied. Early ripening varieties of maize from Wisconsin and Holland ripened a month later than usual after a poor start, and gave satisfactory yields, but the grain had to be artificially dried. Sweet lupins were sown late in order to reduce the proportion of inedible stalk, and even in this unfavourable year gave a useful yield of dry matter. Serradella clearly suffered from the cold season, but nevertheless yielded nearly 2 tons per acre of high protein feed, and promising results were obtained with a new German strain of Jerusalem artichokes. Laboratory work on the sulphur content of the classical barley soils has been completed, and indicates that the sulphur received from rain and other atmospheric sources is sufficient to maintain the sulphur content of the soil.

PHYSICS DEPARTMENT

R. K. Schofield & H. L. Penman

On 1 October 1954, R. K. Schofield was given charge of the Chemistry Department, and H. L. Penman became head of the Physics Department. This report reflects the old order, and falls into the same three parts as formerly.

J. S. G. McCulloch completed his research, supported by an Agricultural Research Council grant, and after a period with the Ministry of Supply will join the staff of the East African Agricultural and Forestry Research Organization in Kenya. F. Silva, of Colombia, has returned home. Short period visitors included Professor C. Manil, from Gembloux, Belgium, Miss Joan Whitmore, from Pretoria, South Africa, Mr. D. E. Patterson, from Leeds University, and Mr. L. E. Danfors, from Uppsala, Sweden. Mr. P. B. Flegg and Miss I. I. Warman from the Mushroom Research Station are working in the department until their new laboratories are ready.

W. W. Emerson and A. W. Taylor received the Ph.D. degree of London University. The latter was awarded a post-doctorate fellowship and is spending eight months at the University of Wisconsin, Madison. H. L. Penman attended the tenth general assembly of the International Union of Geodesy and Geophysics held in Rome.

Agricultural Meteorology

Irrigation and evaporation—General

The Technical Bulletin (referred to in the Report of Rothamsted Experimental Station for 1952) on calculation of irrigation need was published during 1954. This and the results of the first sugar beet experiments and of the Woburn experiment have provided the basis for a number of articles, lectures and overseas broadcasts, and also for a British Association discussion on control of water for increased crop production.

At the request of the Institution of Water Engineers the paper on evaporation over the British Isles (*Quart. J. R. met. Soc.*, 1950, **76**, 372–383; *Rep. Rothamst. exp. Stat. for 1950*, p. 158) was reprinted in their *Transactions*. As a result of the publication of the first report from Lake Hefner, some minor changes have been made in the empirical formulae on which the calculations of potential transpiration are based, the effect of the changes being a reduction of about 5 per cent in estimated values. The revised formulae have been used in calculating values for an evaporation map of parts of Europe (presented to the International Union of Geodesy and Geophysics in Rome) in which the main new physical factor is snow cover for several months in some places. Agreement between evaporation as calculated and as estimated from catchment data was fairly good.

Some of the available data for the Thames Catchment (Report of Rothamsted Experimental Station for 1951) have been reanalysed to show the relative phases and amplitudes of the components in the water balance of the catchment. As a measure of

the continuing inadequacy of estimates of evaporation, it is noted that uncertainty in monthly summer values exceeds the monthly summer discharge of the river.

Irrigation—Woburn

There is a new cropping system.

Grass. The old plots were ploughed up in 1953 and re-seeded with a pure grass strain (S 37 Cocksfoot) in April 1954. Germination was very poor because of drought, and on 13 May all plots were irrigated to save the crop. Subsequent growth was slow because of low temperatures and little sunshine, but by August there was a good stand of grass to provide adequate working material for 1955 and 1956.

Potatoes. Main crop potatoes replaced earlies.

Sugar beet and barley. No change.

The summer of 1954 has been the worst for irrigation since experiments started. Though April was very dry with less than a quarter inch of rain, thereafter rain days were very frequent, so that only in late June and early July was transpiration markedly in excess of rainfall. As a result of watering in that period and subsequent rain, many of the watered plots were maintained at field capacity from mid-July onward with periods of waterlogging and through drainage. The effect of this excess of water appears in the crop yields.

Woburn Irrigation 1954

Crop	Period	Rain (in.)	Irrigation (in.)	Plot	Yield
Grass	17 May–13 Sept.	10·8	0·5	ON_1 26·2 ON_2 38·8	Dry matter (last 3 cuts), cwt./acre
			2·9	CN_1 24·0 CN_2 35·2	
Sugar Beet	29 Apr.–27 Sept.	12·9	—	ON_1 40·9 ON_2 49·6	Sugar, cwt./acre
			1·2	CN_1 43·4 CN_2 46·1	
Barley	29 Apr.–19 July	7·8	—	ON_1 31·3 ON_2 36·8	Grain, cwt./acre
			1·8	CN_1 33·1 CN_2 36·0	
Potatoes	29 Apr.–27 Sept.	12·9	—	ON_1 14·0 ON_2 17·9	tons/acre
			2·2	CN_1 13·3 CN_2 16·9	

Detailed comment is unnecessary. Broadly the irrigation (all before the end of July) has led to slight decreases in yield—a valuable warning.

Micro-meteorology (I. F. Long and J. L. Monteith)

A second set of equipment has been built for continuous recording of air temperature, wet-bulb temperature and wind speed at several heights. After trouble with thermistors, Long has constructed small resistance thermometers of fine-gauge nickel wire, and these have proved so satisfactory in use that small recorded wet-bulb depressions can be relied upon with more certainty than before. He has

also devised a transparent scale so that relative humidity and dew-point temperature can be read quickly from the charts.

One of the recorders has been in the sugar beet of the irrigation experiment at Woburn, but only in one short period has it been reasonable to expect any difference between irrigated plots and non-irrigated plots. The difference was clearly detected, the plot irrigated some days before having a damper, cooler atmosphere within the crop, but no detectable difference above the crop.

The second recorder has been in the Rothamsted potato plots used by J. M. Hirst for his potato blight studies. In addition to Hirst's dew balance, J. L. Monteith has set up a different kind of balance carrying a complete potato plant in soil, continuously weighed: with the balances is equipment for measuring temperature, humidity and wind velocity profiles as supplement to that used by Long. Detail is finer, but is necessarily confined to short periods on chosen nights.

Already it is clear that there are important differences in the dew formation on grass and on potatoes. Monteith's measurements over short grass at Harlington show that on dew nights the soil surface may be about 4° C. warmer than the air at 1 cm. above in the grass cover, and that much of the liquid found on the grass has distilled from the soil surface. Only on rare occasions have the vapour pressure gradients and wind velocities been sufficient to transfer appreciable amounts of water vapour to the leaves from the air above the grass.

For potatoes, where the main cooled surfaces are at the top of a leaf canopy 30–60 cm. above the soil, the vapour pressure gradients within the crop at night are very much smaller than in grass, so that upward distillation is probably negligible. On the other hand, the taller crop projects into a region of greater turbulence, and the possibility of downward transport of vapour is much greater. At present, the rough indication is that the maximum rates of dew formation are about the same on grass as on potatoes at about 3 mg./hr./cm.^{2} of underlying surface. As the condensation rates are an order of magnitude less than those of evaporation on days of moderate sunshine, it is unlikely that dew contributes significantly to the water resources of the growing crop.

Soil Physics

(*a*) Soil structure (W. W. Emerson)

Synthetic soil conditioners

The new sodium saturation test for soil stability (Report of Rothamsted Experimental Station for 1953) has been applied to measure the increase in crumb cohesion induced by the addition of various high-molecular-weight substances. Soils for testing have been taken from farm plots that have been continuously cropped without either manure or fertilizer for 80 years, one being acid (pH 5·3) and the other calcareous (pH 7·2). Natural structure was very poor.

Of the chemical compounds tested, some, such as casein and egg albumin, made the crumbs very difficult to wet, but produced no increase in crumb stability. Others gave positive increases, and

four have been examined in detail: sodium alginate, polyvinyl alcohol, polyacrylic acid, and a co-polymer of vinyl acetate and maleic acid (Krilium CRD-186).

Sodium alginate was found to be effective only if the soil was first sodium saturated. It is presumed that attachment to the soil was prevented in the presence of calcium by the precipitation of the alginate as calcium alginate. The calcareous soil was completely stabilized, the crumbs remaining permeable to distilled water, by the addition of 0·2 per cent by weight of the four polymers to the soil. CRD-186 was even more efficient on the acid soil, stabilization being induced at 0·02 per cent by weight. This accords with field experiments with CRD-186, where the only visible effect on soil structure has been on the acid fields, and not on those containing free $CaCO_3$. The quantity of polyvinyl alcohol needed to stabilize the acid soil was 0·1 per cent by weight.

The mechanism of crumb stabilization is being studied. A previous suggestion of calcium ion " bridges " may be discarded, as the polymers are equally effective when only sodium ions are present. It has been found that the polyvinyl alcohol forms inter-planar compounds with the clay. The other polymers may act differently, possibly being linked by hydrogen bonds to the hydroxyl and oxygen atoms exposed along the edge faces of the clay crystals.

Soil structure field experiment

The four-years-old grass and lucerne plots, ploughed in the autumn of 1953, were sown to spring beans. There were very large differences in yield between these plots and those previously fallow, but there were also large differences in potash status. Similar comparisons for 1954/55 will include an attempt to remedy the potash inequality before the beans are sown.

The effect of liming on crumb cohesion

It has been found that natural crumbs from mildly acid Rothamsted fields are much more stable than those from fields containing free $CaCO_3$. This suggests that a given amount of organic matter is more effective under acid conditions, in agreement with laboratory results for CRD-186.

If the crumbs *are* dispersed by mechanical action, reflocculation can be induced by $CaCl_2$ at a concentration of $2 \times 10^{-3}M$, which is virtually independent of pH. In the field, in the presence of free $CaCO_3$, the concentration of CO_2 in the soil atmosphere will normally maintain a Ca^{++} concentration higher than this in the soil solution. Hence any dispersed clay will be more easily reflocculated in a calcareous soil.

Double-layer theory

The Gouy–Chapman theory has been extended. Previously it has been worked out to give the repulsive force between similar charged plates in a symmetrical electrolyte (e.g., both ions monovalent, or both divalent). The equations have now been solved exactly for 1 : 2 and 2 : 1 electrolytes, and numerically for all other cases. The corresponding attractive forces for oppositely charged plates have been evaluated for symmetrical electrolytes.

(*b*) Clay crystal structure (G. H. Cashen)

Positive charges on the edge faces

The work on kaolin has been continued. The method used attempts to mask the negative isomorphous charge by large organic cations (cetyl trimethyl ammonium) which are adsorbed on the cleavage faces : in the acid range, therefore, any pH changes occurring on addition of a neutral salt to the suspensions should be governed by the positive charges on the edge faces, i.e., a rise in pH should be obtained if there are positive charges present. Previous results were unreliable because of a drift in pH, most marked with those samples of kaolin considered to be most carefully purified, but efforts to find the causes of the instability have met some success. Two changes in technique—the use of polythene containers, which has eliminated contamination by traces of alkali from glass, and the use of highly concentrated suspensions—have together cut the drift down to a very small scale. The positive changes in pH on adding salt to acid kaolin suspensions can now be measured with some confidence, and confirm the existence of positive charges on the kaolin crystals in acid suspensions. The increase is about 0·2 pH units, and is largely independent of the nature of the pre-treatment of the samples of kaolin so far examined.

As the working pH is increased there comes a value sufficiently alkaline for the edge face charges to be negative, and then addition of salt causes a decrease in pH value. An analogous transition value can also be found for a change in adsorption of chloride ions as the pH is altered. The transition pH is higher for the chloride method : an explanation of the discrepancy is being sought.

Physical Chemistry

(A. W. Taylor and F. Silva)

The flame photometer (for potassium) and the versenate titration (for calcium and magnesium) have been used to determine the concentration of ions in solutions in equilibrium with soil samples for total concentrations of chlorides ranging from 1 to 50 $\times$ 10^{-3} normal. The results show that the activity of the magnesium ion varies directly as the activity of the calcium ion, whereas the activity of the potassium ion varies as the square root of the activity of the calcium ion. The relative concentrations of calcium and potassium were found to depend on temperature, a higher proportion of potassium being found at higher temperatures.

A simple and rapid test has been used to detect inequalities in the potash status of different plots of a field. A 25-g. sample of the soil is shaken for one hour with 50 ml. of 0·01*M*-$CaCl_2$ solution, filtered, and then the potassium concentration in the filtrate is determined. The concentrations given by soils from different plots on the Rothamsted farm vary from 5 $\times$ 10^{-5} to 2 $\times$ 10^{-3}, and show residual effects from potassium salts and dung applied as much as seventy years ago.

There has been further investigation of the very small concentra-

tions of phosphate ions brought into solution when soil samples are shaken with 0·01*M*-$CaCl_2$ solution. The concentrations are not as reproducible as could be desired, and tend to diminish when the solution remains in contact with the soil for several days. This matter still needs further study.

CHEMISTRY DEPARTMENT

R. K. Schofield

The grievous loss which the Station sustained through the sudden death of E. M. Crowther on 17 March particularly affected the Chemistry Department of which he had been the Head since 1927. R. G. Warren, G. W. Cooke and B. Benzian immediately shouldered additional responsibilities, and thus ensured the effective continuation of the work. R. K. Schofield became Head on 1 October.

Fertilizer Placement

Horticultural crops

G. W. Cooke, F. V. Widdowson and J. C. Wilcox continued their field experiments on horticultural crops in which the effects of placed and broadcast fertilizers have been compared. National Compound Fertilizer No. 1 (7 per cent N, 7 per cent P_2O_5, 10·5 per cent K_2O) was used for all crops. Placing fertilizer in one band beside the seed gave higher yields than broadcasting in experiments on cabbage, lettuce, broad beans, runner beans, maize and onions. The differences in favour of placement were significant in the experiments on broad beans, runner beans, maize and onions.

Thirty experiments on horticultural crops have been carried out from 1952 to 1954, the results are summarized below by averaging all experiments on each crop. There have been worthwhile gains from placing as compared with broadcasting for all crops except beetroot and French beans. Placed fertilizer gave higher yields than broadcast fertilizer in twenty-two experiments, in ten of these experiments placing was significantly better than broadcasting. There were no experiments where placing was significantly inferior to broadcasting.

Table 1

Experiments on horticultural crops 1952–54

Crop	No. of experiments	Unmanured yield	Response to broadcast fertilizer	Gain from placing over broadcasting
		Mean yields, cwt./acre		
Cabbage	4	97	47	23
Lettuce	6	124	18	23
Beetroot	3	58	5	4
Onions	2	209	24	28
Maize	2	103	7	14
Broad beans	5	64	2	12
French beans ..	3	72	−5	5
Runner beans ..	5	96	7	7

Placement has two advantages for horticultural crops. First, the amounts of fertilizer needed to produce a given yield are often smaller when the dressing is placed than when it is broadcast; for broad beans, placed fertilizer has increased yields in experiments

where broadcast dressings have had little effect. Secondly, many of the crops grown with placed fertilizer were ready to harvest before those grown with broadcast fertilizer. These advantages may be very profitable where high-value cash crops are grown, and will speedily repay the cost of special placement drills. The experiments have been carried out on ordinary arable land carrying rotations of farm crops with occasional horticultural crops. No experiments have been carried out on intensively-cultivated, long-established market-garden land. Where such soils have received heavy dressings of manures it is not likely that fertilizers will markedly increase crop yields, and the advantages of placement are likely to be smaller.

In a subsidiary series of experiments, comparisons have been made of mid-season top-dressings of nitrogen fertilizers applied for brassica crops. Dressings localized near to the base of each plant have had little advantage over dressings applied by the usual method of broadcasting over all the surface of the soil.

Cereals

Four experiments on spring cereals tested a nitrophosphate (made with addition of ammonium sulphate) against an equivalent mixture of granular superphosphate with " Nitro-Chalk ". The fertilizers were applied both broadcast and combine-drilled. Superphosphate plus " Nitro-Chalk " again gave higher yields than equivalent dressings of nitrophosphate, but the differences were smaller than in previous years. Thirteen experiments on wheat and barley were made from 1952 to 1954 to compare superphosphate (plus equivalent nitrogen) with nitrophosphate. The results are summarized in Table 2 by averaging all experiments.

TABLE 2

Experiment with cereals 1952–54

	Yield of grain, cwt./acre
Mean yield with nitrogen only	22·1
Increase from superphosphate plus " Nitro-Chalk "	
Broadcast	2·8
Combine-drilled	4·7
Increase from nitrophosphate	
Broadcast	1·8
Combine-drilled	4·0
Increase from drilling over broadcasting	
for superphosphate	1·6
for nitrophosphate	2·1

Both nitrophosphate and superphosphate increased yields significantly at seven of the thirteen centres when the fertilizers were drilled with the seed. When the fertilizers were broadcast there were significant increases from superphosphate at seven centres, but nitrophosphate increased yields significantly at only three of the centres. In all years phosphate drilled with the seed improved establishment and early growth. Generally water-soluble phosphate gave better growth in the early stages than insoluble phosphates. Where a quick start is important for cereals, water-soluble phos-

phates are to be preferred; but if nitrophosphates are used, they should be drilled with the seed.

In two experiments on barley grown on medium-textured soils there were good responses to nitrogen, and combine-drilling of ammonium sulphate gave higher yields than broadcasting the dressings on the seedbed. Top-dressings of "Nitro-Chalk" applied in May gave large increases in yields, even where ammonium sulphate had been applied in the seedbed. In two experiments on wheat grown on heavy, badly-drained soils the effects of nitrogen were much smaller. Combine-drilling gave higher yields than broadcasting in one of the experiments, but top-dressing did not increase the yields.

Potatoes

In one experiment on potatoes placing of both nitrogen and potash fertilizers gave higher yields than broadcasting the dressings on the seedbed before planting. In another experiment placing nitrogen and potash was superior to broadcasting when low rates of dressing were used, but at high rates broadcasting gave higher yields.

In seven experiments on main-crop potatoes 1·0 cwt. N/acre was sufficient for maximum yields. When this amount of nitrogen was split, half being applied (as ammonium sulphate) at planting and half broadcast (as "Nitro-Chalk") when the potatoes were earthed-up, the top-dressing did not increase yields. When the full dressing of nitrogen was applied at planting, later top-dressings decreased yields. Similar results were obtained from experiments carried out in 1953. There is no justification for applying mid-season top-dressings of nitrogen for potatoes.

In three of the experiments on main-crop potatoes nitrogen fertilizers did not give worth-while increases in yield. Of four cereal experiments, there were no benefits from nitrogen at two of the centres. These results emphasize the difficulty of making practical recommendations for using nitrogen. There are no satisfactory soil tests for "available nitrogen" to provide guidance on manuring. British farmers spend about £20 million annually on nitrogen fertilizers. Although this investment yields a handsome return on average, it is difficult to forecast the likely gains on individual fields. Any excess of inorganic nitrogen may be lost during winter before another crop is grown. There are large potential gains in fertilizer efficiency, and savings to the farmers, from any improvements in practical advice on manuring which current research can provide.

Radio-Tracers in Soil and Fertilizer Research

G. E. G. Mattingly and F. V. Widdowson have conducted four experiments near the same sites and with the same crops as in 1953; there were only minor alterations of the designs used previously. Results are given below for the grain yield of barley at one site in both years, together with the estimates of uptake of placed radioactive superphosphate, broadcast inactive phosphate fertilizers and A-value increase due to the broadcast fertilizer. The uptake of

placed active fertilizer, which was drilled with the seed, was estimated from radiochemical assay of plant samples; the apparent uptake of broadcast fertilizers was estimated by difference.

TABLE 3

Experiments on barley 1953 *and* 1954

Radioactive superphosphate 0·1 cwt. P_2O_5/acre, placed

Unlabelled fertilizer broadcast, cwt. P_2O_5/acre	Year	nil	Superphosphate 0·3	Superphosphate 0·6	Di-calcium phosphate 0·45	Rock phosphate 0·45	S.E.
Yield, dry grain, cwt./acre	1953	20·5	22·2	24·0	23·0	21·7	±0·477
	1954	12·3	19·8	20·1	19·3	12·8	±0·595
Uptake of placed radioactive superphosphate, cwt. P_2O_5/acre	1953	0·015	0·015	0·013	0·015	0·015	±0·0012
	1954	0·014	0·016	0·012	0·013	0·016	±0·0014
Apparent uptake of broadcast phosphate, cwt. P_2O_5/acre	1953	—	0·016	0·033	0·023	0·006	±0·014
	1954	—	0·074	0·082	0·067	0·021	±0·012
Increase in A-value due to broadcast fertilizer, cwt. P_2O_5/acre	1953	—	0·030	0·360	0·156	−0·030	±0·100
	1954	—	0·319	0·664	0·556	0·008	±0·133

There were significant responses to the broadcast phosphate fertilizers, except rock phosphate, in the presence of 0·1 cwt. P_2O_5 drilled with the seed in both years on this site; responses were much greater in 1954, when a cold, wet summer resulted in slow growth, particularly of late-sown crops.

In both years the crop took up about 15 per cent of the phosphorus drilled with the seed, and this quantity was almost independent of the presence of the broadcast fertilizer. The most interesting result, however, is the markedly different utilization of the broadcast fertilizers in the two years. In 1953 the apparent uptake of broadcast superphosphate was about 5 per cent of that applied, that is about one-third of the uptake of the combine-drilled fertilizer. In 1954, however, about 17 per cent of the broadcast fertilizer was apparently used (average of 0·3 and 0·6 cwt. P_2O_5 broadcast), a figure which is slightly higher than the uptake from combine-drilled phosphate.

The increase in A-values due to the broadcast fertilizers in the two years are markedly different. In 1953 broadcast superphosphate was only one-third as effective as placed fertilizer, while in 1954 they appear to have been equally effective. Substantially similar results have been obtained from the other field experiments, the results of which are not, however, yet completed. These experiments illustrate one use of fertilizers labelled with ^{32}P in determining in one experiment the relative efficiency of a placed and broadcast fertilizer. This information can be obtained if necessary by analysis of only small unweighed crop samples taken before harvest.

G. E. G. Mattingly has completed the pot experiment on ryegrass made to test the residual effects of superphosphate and Gafsa mineral phosphate to which reference was made in the 1953 report. There was a steady decline in the yield and phosphorus uptake of three month's growth with the lapse of time up to three years since superphosphate had been applied to the soil. Lower and substantially constant yields and phosphorus uptakes were obtained from the soils which had received Gafsa mineral phosphate. A small known amount of radioactive phosphorus had been very evenly distributed through the soil in each pot, and measurements were

made of the radioactivity in the cut grass. The dilution of the tracer phosphate by soil phosphate, which is expressed by the A-values given in Table 4, was greatest for the grass grown in the soil which had most recently received the dressing of superphosphate, and declined with the lapse of time in the same way as the yields and phosphorus uptakes. If there were no loss, 1·2 cwt. P_2O_5/acre applied as superphosphate to a depth of 6 inches would raise the A-value of the top soil by some 4 mg. P/100 g. The decline in three years is about three-quarters of this amount.

TABLE 4

Pot experiments on ryegrass

(400 g. soil per pot)

Soil	Treatment	Years since last application	Yield, g./pot	Uptake, mg. P/pot	"A-value", mg. P/100 g. soil
Hoosfield Four-course rotation, 4% $CaCO_3$	Superphosphate 1·2 cwt. P_2O_5/acre every fifth year, total application 6 cwt. P_2O_5/acre	0	6·43	10·70	11·6
		1	6·64	9·22	10·2
		2	6·28	8·58	9·8
		3	5·86	6·54	8·3
		4	5·74	6·58	8·8
Hoosfield Four-course rotation, 4% $CaCO_3$	Gafsa mineral phosphate 1·2 cwt. P_2O_5/acre every fifth year, total application 6 cwt. P_2O_5/acre	0	3·94	3·78	6·8
		1	3·50	4·13	6·7
		2	3·39	3·29	6·8
		3	3·03	2·71	6·1
		4	3·48	3·31	6·5
	S.E.		±0·376	±0·659	±0·43
Hoosfield Exhaustion land, 3% $CaCO_3$	No phosphate	—	1·63	1·62	3·4
	Superphosphate total application, 28 cwt. P_2O_5/acre	53	5·83	8·56	9·4
	S.E.		±0·103	±0·300	±0·13

Soils taken from two of the Hoosfield Exhaustion plots were included in this pot experiment. The values obtained for the plot which has had no phosphate since 1856 are lower than those for the Four-course plots, which have only had mineral phosphate since 1928 but occasional dressings of dung before that date. By contrast, the values for the plot which received annual dressings of superphosphate between 1856 and 1901 fall within the range of the values given by the Four-course plots, which have received superphosphate more recently but considerably less in total amount.

O. Talibudeen has made laboratory experiments with some of the same soils. Samples were continuously shaken in 0·001*M*-ammonium citrate solution to which a small known amount of radioactive phosphorus had been added. After different lengths of time measurements were made to determine: (*a*) how much soil phosphate had gone into the solution, and (*b*) what fraction of the radioactive phosphorus remained in the solution (the rest having been taken up by the soil particles). Values obtained by dividing (*a*) by (*b*) provide estimates of the amounts of labile orthophosphate in the different soils. Provisionally the values obtained after shaking 0·5 or 1 g. of soil in 100 ml. of the solution for 150 hours have been used because no increase was detected on prolonging the shaking to 200 hours.

In Table 5 the values so obtained are given under the heading P_e 0·001*M*, and may be compared with A-values obtained in pot experiments. The results indicate that essentially the same category of phosphate is estimated by both methods.

TABLE 5

Comparison of laboratory and pot experiments

Soil	Treatment	mg. P/100 g. soil A-value (pot expts.)	P_e 0·001*M*	P_e 0·1*M*
Hoosfield Exhaustion land	No phosphate	3·4	4·8	6·5
	Farmyard manure before 1901	10·0	11·2	—
	Superphosphate before 1901	9·4	11·0	34·3
Highfield	—	16·0	17·0	—
Sawyer's Field	—	6·0	9·2	17·3

In further experiments increasing concentrations of ammonium citrate were used, and values for three of the soils obtained after 150 hours in 0·1*M*-ammonium citrate are recorded in Table 5 under the heading P_e 0·1*M*. With the more concentrated solution a much higher value was obtained for the soil of the Exhaustion plot, which still contains considerable residues from applications of superphosphate made before 1901, whereas there was very little increase in the value for the soil which has received no manure or phosphate fertilizer for over a century. These soils contain calcium carbonate, and it would appear that the stronger solution is capable of dissolving precipitated calcium phosphate. It also dissolved some phosphate from the acid soil of Sawyer's Field. Evidently the values obtained with the weaker solution more nearly reflect the field condition of the soils.

A procedure for the quantitative estimation of radioactive calcium (^{45}Ca) as the oxalate was worked out. The technique developed ensured reproducible precipitation, filtration and packing of samples with a mass density up to 70 mg. CaC_2O_4/sq. cm. approximately. The reproducibility of the counting rate was within the error of the counting apparatus. From this it was possible to define the optimum conditions for the estimation of ^{45}Ca, to plot a correction curve for different weights of CaC_2O_4 and to give approximate figures for the self-absorption coefficient, the half thickness of absorption and the range of the weak-energy β-emission from ^{45}Ca. (R. C. Chen.)

SOLUBILITY RELATIONSHIP FOR FLUORAPATITE

F. S. C. P. Kalpagé continued his study of the solubility of finely divided Gafsa phosphate rock in acid and neutral solvents. He confirmed that when an excess of the phosphate rock remains undissolved, the resulting solution approaches a state of equilibrium with the residue of fluorapatite and fluorspa. The solutions obtained with 0·1*M*-citric acid, being better buffered, were less disturbed by the slow dissolution of calcium carbonate, and so got nearer to the state of equilibrium than the solutions obtained with 0·1*M*-hydrochloric acid. For all the solutions examined, the equilibrium state is characterized by the relationship

$$2\mathrm{pH} - \frac{3}{2}\mathrm{pCa} - \mathrm{pH_2PO_4} = 1{\cdot}8$$

pCa and pH_2PO_4 are the negative logarithms of the activities of the calcium ions and the dihydrogen phosphate ions respectively. Both were computed without serious error from the observed concentra-

tions in dilute hydrochloric and citric acids with the aid of the well-known equation of Debye and Hückel. When ammonium citrate and sodium versenate are used, pCa cannot be obtained so simply, because calcium ions are sequestered in these solutions, and the results show very clearly that the solvent action of these neutral solutions is largely due to lowering of the activity of the calcium ions through complex formation.

The newly found relationship rules out the possibility which was previously entertained that dicalcium phosphate might have been precipitated as a coating on the residue not dissolved in 0·1*M*-hydrochloric acid. Brushite (dicalcium phosphate dihydrate) is the only form of dicalcium phosphate which could have been precipitated. Its solubility relationship is $pH - pCa - pH_2PO_4 = 0{\cdot}6$. Thus brushite can be formed from fluorapatite in the presence of fluorspa only when $pH - \frac{1}{2}pCa < 1{\cdot}2$ and $\frac{1}{2}pCa + pH_2PO_4 > 0{\cdot}6$. For the second condition to hold, the concentration of dihydrogen phosphate ions must exceed 0·5*M*, and it is clearly impossible for this concentration to be produced starting with hydrochloric or citric acid as dilute as 0·1*M*. Much stronger hydrochloric acid is used in the manufacture of dicalcium phosphate from phosphate rock.

The finding of a quantitative solubility relationship for fluorapatite in the presence of fluorspa is an important step in the search for rational analytical procedure whereby the amount of dicalcium phosphate in a fertilizer can be determined without interference from any apatite that may be present. It also helps to define the soil conditions in which phosphate rock is an effective fertilizer.

Nutrition Problems in Forest Nurseries

B. Benzian and J. E. A. Ogborn, in collaboration with the Research Branch of the Forestry Commission, have continued work planned by E. M. Crowther. Five series of experiments in which rates of application of phosphate and potash had been tested over several years were concluded in 1954. Experiments which had received annual dressings of superphosphate showed remarkably constant responses to P from season to season and centre to centre (ranging from very acid to almost neutral soils). Averaging all nurseries and seasons, the response in mean height to 6 g. P/sq. yd. was very close to $\frac{1}{2}$ inch. Depending on the number of plants per square yard and the moisture content of the seedlings, a response of $\frac{1}{2}$ inch would be equivalent to between 5 and 10 cwt. dry matter/acre. Up to the highest rate of phosphate tested (6 g. P/sq. yd. or approximately 7 cwt. superphosphate/acre) the responses show no signs of falling off, and a new series of experiments has therefore been laid down to test higher rates. Responses to potash were smaller and varied more between centres.

A few years ago a bright yellow discoloration of Sitka spruce was identified as magnesium deficiency. Since 1951 magnesium has been tested annually in several nurseries. The intensity of the symptoms and the time of their appearance has varied from year to year, and 1954 was the first season in which several experiments showed a significant response in height.

In nurseries in which growth of Sitka spruce and other conifer seedlings is normally very poor, even on plots with ample manuring,

such treatments as steam, formalin and chlorpicrin have yielded excellent seedlings. These treatments have usually been applied either in December after the seedbeds had been cleared of the previous season's crop or in February, 3–4 weeks before sowing. As bad weather may prevent, or at least delay, application of treatments, and hence sowing, a series of experiments was started in which applications were made in the summer (June), autumn (October/November), early winter (December) and early spring (February).

Formalin was applied as a drench, containing either 167 or 333 ml. of formaldehyde, and chlorpicrin injected at rates of either 24 or 48 ml./sq. yd. The results, averaging rates of application, are given in Table 6.

TABLE 6

One-year seedlings of Sitka spruce 1954

	Mean height, inches		
	Kennington K 64	Ampthill Am 34	Ringwood R 64
Untreated	1·7	2·1	1·5
Formalin			
June	2·0	2·3	2·0
November	3·1	2·9	2·4
December	3·0	3·3	2·5
February	2·7	3·3	2·4
Chlorpicrin			
June	2·4	2·7	2·4
November	2·8	2·7	2·3
December	2·9	2·8	2·3
February	2·7	3·1	2·2
S.E.	±0·11	±0·08	±0·08

Both formalin and chlorpicrin increased height at all three centres. In the case of formalin there were considerable differences between the dates of application, the June treatment being inferior to the remainder at all three centres. The responses to chlorpicrin appear to depend far less on the time of application, and at Ampthill and Ringwood the June applications of chlorpicrin are similar to the November and December applications. There was no difference between the early November and the December applications of the two materials in five cases out of six.

At Ampthill none of the treatments affected plant number, but at Ringwood the spring application of chlorpicrin caused a considerable reduction in stocking. Such a reduction in plant number has been noticed on previous occasions when treatments were applied only a few weeks before sowing, and this is another reason why it became necessary to test applications at other times of the year.

If the satisfactory results from summer applications of chlorpicrin and autumn applications of both formalin and chlorpicrin are confirmed, they may have considerable bearing on nursery practice. It is part of the Forestry Commission's policy to fallow annually one or more sections in many of the older nurseries. At present the fallow period is devoted mainly to the destruction of weeds and insect pests, but it may become possible to apply large-

scale treatments of formalin or chlorpicrin during the fallow period to some of the nurseries where these treatments are likely to be beneficial.

The search for safer and cheaper alternatives to formalin and chlorpicrin has continued. CBP 55 (chlorobromopropene) has given promising results, both injected and as a drench, in an experiment on 1-year Sitka spruce seedlings at Ampthill. The injection treatments of both chlorpicrin and CBP 55 were applied at rates of 12 and 24 ml./sq. yd. CBP 55 drench consisted of either 30 or 60 ml. of the emulsible concentrate in 4 l. water. The results averaging rates of application are given in Table 7.

TABLE 7

One-year seedlings of Sitka spruce 1954

	Ampthill (Am 47)	
	Mean height, inches	No. of plants per sq. yd.
Untreated	2·4	1280
S.E.	±0·10	±70·6
Applied in February		
Chlorpicrin injected ..	3·3	1462
CBP 55 injected	3·0	1516
CBP 55 drench	3·3	1558
S.E.	±0·15	±99·8

As the inhibition of nitrification may play some part in the benefit derived from such materials as formalin and chlorpicrin, a number of substances known to inhibit nitrification were tested in pot experiments. One of these materials, potassium dichromate, had shown some promise in pot experiments in 1952 and 1953, and was therefore tested in the field. In three experiments at Ampthill, Old Kennington and Ringwood 10 g./sq. yd of potassium dichromate dissolved in water were applied by power spray to the surface of the plots in December. Dichromate increased both height and plant number of Sitka spruce seedlings as shown in Table 8.

TABLE 8

One-year seedlings of Sitka spruce 1954

	Mean height, inches			No. of plants per sq. yd.		
	Kennington K 74	Ampthill Am 41	Ringwood R 69	Kennington K 74	Ampthill Am 41	Ringwood R 69
Untreated ..	2·2	2·4	0·7	513	1558	771
Potassium dichromate	2·5	2·6	1·1	742	1585	902
S.E.	±0·05	±0·08	±0·05	±41·8	±46·3	±29·8

Eelworm examinations of seedlings and transplants at Ringwood Nursery were continued by J. B. Goodey. The infestations in 1954 were generally lower than they had been in previous years.

Mr. D. M. Griffin, working under Dr. Garrett, Director of the Sub-Department of Mycology, Botany School, Cambridge, has made mycological examinations of plants from many of the experiments with the aim of devising a suitable system of root disease rating,

together with a method for identifying the particular fungal pathogens concerned.

Soil Organic Matter

J. M. Bremner has further examined the view that the humic fraction of soil organic matter consists largely of lignin or lignin-derived material associated with protein. One of the most characteristic reactions of plant lignin is that it gives substantial yields (as much as 25 per cent) of phenolic aldehydes when oxidised with nitrobenzene in alkaline solution. Paper chromatographic analysis of the products formed by alkaline nitrobenzene oxidation of humic acid preparations from eight different soils did reveal the presence of vanillin, syringaldehyde and *p*-hydroxybenzaldehyde, but the amounts of phenolic aldehydes detected were very small, the highest yield, about 1 per cent, being obtained from a peat humic acid. Further evidence that plant lignins are drastically altered in the processes leading to the formation of soil organic matter has been obtained from a study of chemical changes during the biological decomposition of oat straw composted with ammonium carbonate. This showed that although decomposition of the straw was not accompanied by any substantial decrease in the total amount of lignin as estimated by the usual methods of plant analysis it was accompanied by a very marked decrease in the yield of phenolic aldehydes obtained by alkaline nitrobenzene oxidation.

Attempts to isolate protein from nitrogen-rich humic acid preparations, e.g., by removal of the non-protein material with mild oxidising agents such as chlorine dioxide, have not so far been successful, but substances with the properties of peptides have been detected by paper chromatographic analysis of the products liberated by partial hydrolysis of humic acid preparations with concentrated hydrochloric acid at 35° C.

Previous work on the alkaline decomposition of amino-acids (see the Report of Rothamsted Experimental Station for 1950, p. 42) was extended by a study of the effect of hot alkali on the following β-hydroxy-α-amino acids: glucosaminic acid, β-hydroxyaspartic acid, β-hydroxyglutamic acid, β-hydroxyvaline, β-hydroxynorvaline, β-hydroxyleucine, β-hydroxynorleucine, β-phenylserine, β-p-hydroxyphenylserine. The results showed that when a β-hydroxy-α-amino acid ($R{\cdot}CH(OH){\cdot}CH(NH_2){\cdot}COOH$) is heated with alkali it decomposes with the formation of glycine and, in some cases, the amino-acid $R{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$. Earlier work on nitrogen transformations during the biological decomposition of straw composted with inorganic nitrogen and on the chemical nature of the nitrogen in the humic fraction of soil organic matter was completed and prepared for publication.

P. W. Arnold has worked on the isolation and characterization of the principal organic phosphorus compounds which occur in soil. In British soils it is usual for about one-half of the total phosphorus to be present in organic combination, and information on the role of organic phosphorus in soil fertility problems is required.

Although a sodium hydroxide solution, usually preceded by a dilute acid leaching of the soil, is the most efficient organic phosphorus extractant, the unavoidable presence of the large amount

of organic matter in the sodium hydroxide extract greatly hinders attempts to proceed further with the characterization of the organic phosphorus compounds. It was found that cold concentrated hydrochloric acid extracted most of the organic phosphorus from soils without bringing about much hydrolysis; moreover, a comparatively small part of the total soil organic matter entered the extract. Practically all the phosphorus-containing organic matter extracted by concentrated hydrochloric acid is insoluble in 70 per cent ethanol, and inositol phosphate can be released from it by alkaline hypobromite oxidation. It is pertinent to record that additions of a few parts per million of inositol hexaphosphate to soils can be recovered quantitatively by a simple acid extraction without an alkaline hypobromite oxidation, but none of the soil's native inositol phosphate is isolated by such a procedure. It would appear that in soil the native inositol phosphate is linked to an organic nitrogenous moiety in an, as yet, unknown way.

In order that the inositol-bound phosphorus isolated from soil could be examined in detail a paper electrophoresis technique was employed. Microgram quantities of mono-, di-, tri- and tetraphosphorylated inositols have been separated from synthetic mixtures of the phosphates and from partially hydrolysed inositol hexaphosphate (phytic acid), but as the penta- and hexaphosphates migrate at the same speeds, no separation of these two latter phosphates has been possible by the electrophoretic technique. After cold alkaline hypobromination it has been found that the inositol phosphate isolated from soil contains at least five phosphorus atoms per inositol molecule, and minimal values for the inositol phosphate contents of a variety of British soils account for between one-third and two-thirds of the total organic phosphorus contents. It is possible that inositol mono-, di-, tri- and tetraphosphates are present in small concentrations in soils, but such compounds may also appear as artefacts when extraction conditions are too drastic.

As well as inositol-bound phosphorus, organic phosphorus occurs in soil in a form which has not yet been separated from the so-called humic fraction of soil. The only information available is that about 15 per cent of the total organic phosphorus is in this form in an acid peaty soil, but it is by no means certain that it constitutes a definite category of phosphorus. Only trace amounts of adenine and guanine have been isolated from the hydrolysates of well-humified soils, from which it has been calculated that not more than about 5 per cent of the total organic phosphorus of such soils can be present in nucleotide combination.

K. Shaw has continued to work on the decomposition of mat on old permanent pasture, using samples of mat separated from the underlying mineral soil on the unlimed sections of Park Grass Plots 1, 4_2 and 11_1. The rates of decomposition of the mat from plots 1 and 11_1, which have received annually 2 and 6 cwt./acre of ammonium sulphate respectively for almost 100 years, were followed by measuring the carbon dioxide and mineral nitrogen produced by incubation of the mat when mixed with its underlying mineral soil. Although the nitrogen contents of the mat from the two plots were appreciably different (plot 1, 1·51 per cent N; plot 11_1, 1·79 per cent N), the rates of decomposition as measured by production of

carbon dioxide or mineral nitrogen were very similar. The addition of sufficient calcium carbonate to bring the pH of the mixture of mat and mineral soil to about 7 did not affect the mineralization of the nitrogen in the mat, but did increase its decomposition to carbon dioxide. The production of carbon dioxide and mineral nitrogen by the mat from plot 1 was found to be substantially greater in the absence than in the presence of mineral soil.

Satisfactory micro-diffusion methods for the determination of ammonia and nitrate in soil extracts have now been developed. The ammonia is extracted by Olsen's method, and determined by distillation with magnesium oxide at 25° C. in a modified Conway micro-diffusion unit. Ammonia plus nitrate is determined on a separate sample of the same extract by reduction of the nitrate with titanous hydroxide and subsequent distillation with magnesium oxide, the reduction and distillation being carried out at 25° C. in a modified micro-diffusion unit. The methods are applicable to coloured extracts, and have the advantage that they require only a small volume of soil extract and permit the rapid analysis of a large number of samples.

S. G. Heintze has used neutral disodium monocalcium versenate to extract manganese from alkaline organic soils. The amounts obtained after 1 hour's shaking agree closely enough with those obtained in the same time with alkaline pyrophosphate to suggest that little if any reduction of tri- or tetravalent manganese has taken place. These values are therefore taken to represent divalent manganese complexed by the soil organic matter.

The nature of the organic complexes of manganese has been further studied with the aid of paper electrophoresis. Complexes which migrate to the cathode were made by the reaction of manganous sulphate with humic acid prepared from an alkaline fen soil and a sample of commercial lignin " Meadol " exhibited the same characteristic.

General

G. W. Cooke spent 6 weeks at the headquarters of the Food and Agriculture Organization of the United Nations in Rome and prepared the *Annual review of world production and consumption of fertilizers* for 1954. He was also invited to attend the General Assembly of the International Centre of Chemical Fertilizers held in Zürich in October. He read a paper on " The importance of organic matter in relation to crop nutrition ".

J. M. Bremner worked for 3 months at the Institut für Biochemie des Bodens, Forschungsanstalt für Landwirtschaft, Völkenrode, Braunschweig, Germany, and then made a 1-month tour of other agricultural research centres in Western Germany. He also attended and contributed to the Conference on Soil Organic Matter held at Völkenrode. The visit to Völkenrode was at the invitation of Prof. W. Flaig, Director of the Institut für Biochemie des Bodens, and was supported by a grant from the German Ministry of Food, Agriculture and Forestry. His tour of agricultural research stations in Western Germany was made with the assistance of a travel grant from the Agricultural Research Council.

P. W. Arnold joined the staff at the beginning of the year. J. C.

Wilcox of the National Agricultural Advisory Service, J. Bolton of the Colonial Agricultural Research Service, and P. W. W. Daborn of the Forestry Commission were further seconded for field work. F. S. C. P. Kalpagé was awarded the Ph.D. degree of London University, and returned to Ceylon.

PEDOLOGY DEPARTMENT

A. Muir

A. Muir visited Nigeria at the invitation of the Colonial Office and the Nigerian Government, and later attended the 2nd Inter-African Soil Conference as a British delegate and the 5th Congress of the International Society of Soil Science, both held in the Belgian Congo. G. Brown and R. Greene-Kelly attended the 3rd International Crystallographic Congress in Paris. D. M. C. MacEwan has been given leave of absence to take up a post in the University of Granada. Mr. S. Singh was awarded the degree of Ph.D. by London University and has now returned to India, and Prof. J. L. White has returned to Purdue University after his year's work in the department. Dr. D. H. Ya'alon of the Hebrew University, Jerusalem is spending one year studying clay mineralogy.

Soil Mineralogy

Nyasaland

A study of the mineralogical composition of a suite of soils from the Lower Shire River area has been carried out with the object of establishing the derivation of the various soils, and seeing whether the variation in soil pattern is dependent on the type of source rock from which they are derived. Altogether, samples from twenty-one profiles have been subjected to mineralogical analysis in order to determine the probable parent materials, and it has been possible to subdivide the area into several provinces showing common characteristics in the mineral assemblages.

(1) The heavy minerals are characterized by a dominance of hornblende with opaque iron minerals abundant. Biotite, apatite, sphene and epidote are prominent, and with zircon and garnet, form the bulk of the accessory minerals. Minor heavy accessories and the light minerals suggest derivation from hornblendic rocks of the crystalline complex.

(2) The heavy residue contains a very high percentage of opaque minerals, with hornblende as the dominant pyrobole. Garnet and zircon are both very common. Together with the accessories and light minerals, the assemblage suggests a mixture of material of Basement Complex origin with either (*a*) material of sedimentary origin having a high percentage of opaque minerals or (*b*) very weathered material of basaltic origin from which the characteristic pyroxenes and feldspars have been eliminated, leaving a residue of iron oxides.

(3) All the samples in this group show the influence to a greater or lesser extent of the contribution of basaltic material, as is shown by the presence of pyroxenes and ore among the heavy minerals, and labradorite among the light minerals; zeolites and small amounts of volcanic glass also occur.

(4) One profile has been examined in this area : the sands yield only a small quantity of heavy residue, of which opaque minerals make up more than 50 per cent. The high proportion of the " resist-

ant" heavy minerals, a comparative scarcity of pyroboles and a high quartz content suggest an origin from sedimentary deposits.

(5) The sands in this province yield abundant heavy residues (up to 20 per cent by weight), with hornblende and/or garnet the dominant minerals. All these soils are probably of Basement Complex origin. (I. Stephen.)

Clay Mineralogy

Soil morphology and mineralogy

A study of thin iron pan soils (cf. Crompton, *J. Soil Sci.* **3** (1952), 277) by mineralogical and chemical methods has been started. Attention is being concentrated on the iron pan itself and the immediately adjacent soil to elucidate the nature of the iron pan and its effect on the mineralogy of adjacent materials. The iron pan consists of several distinguishable layers, and it is hoped to investigate these separately. (G. Brown.)

Dickite

In collaboration with Dr. F. Smithson, University College of North Wales, the work on dickite has been continued. A paper on the petrography of the dickite sandstones has been published by Dr. Smithson, and the mineralogical part of this work is now being prepared for publication. Detailed examination of carefully purified samples of dickite from the different geological formations has been carried out. (G. Brown.)

Ion exchange studies

Apart from some studies on the exchange of ions at elevated temperatures in a bomb designed and made in the Department, no further work has been carried out. (R. Greene-Kelly.)

Adsorption by clay minerals

The vapour-phase isotherm studies on montmorillonite have been continued, particular attention being paid to the influence of the macro-structure of the clay on the isotherms. The results have shown that whereas the sorption of water is little affected, the adsorption of non-polar molecules appears to be restricted to the surface readily available, and hence is markedly altered, depending on whether the clay is in blocks or is finely divided. The influence of temperature on the sorption of water has been studied with a view to investigating the influence of the hysteresis present in the isotherms on the calculated heats of sorption. Whilst the results await the comparison with calorimetrically determined heats, it appears that there is a wide variation in heats determined from the isotherms, depending on whether the adsorption or desorption path is followed.

During the year a high vacuum adsorption calorimeter has been constructed to measure the heats of adsorption and heat capacities of water films on montmorillonite. The present model is capable of operating over the temperature range $+30°$ to $-80°$ C., and is thus able to explore the region in which freezing transitions are reported.

The calorimeter is fully adiabatic, having a shield which is automatically maintained at the same temperature as the calorimeter by a galvonometer–photocell control.

In connection with the kaolin–water studies reported last year a heat-of-wetting calorimeter, using a thermistor as temperature-sensitive element, has been designed. When completed, it is hoped that it will be able to measure heat effects of the order of 1 calorie with an accuracy of a few per cent.

The study of the sorption of aromatic molecules by montmorillonite has been completed, and two papers will shortly be published. The work on the sorption complexes of montmorillonite and saturated ring and chain molecules has been continued, the main effort being directed to resolving the problem of the variation in apparent contact distances between the molecule and the silicate sheet surface with the number of atoms in the molecule.

A detailed study has been completed on the pyridine–montmorillonite complex with a spacing of 23 Å. The results suggested that the molecules were arranged in a layer symmetrically between the silicate sheets and supported on either side by molecules oriented normal to the silicate sheet surface. (R. Greene-Kelly.)

Differential thermal analysis

In connection with the chapter on the montmorillonite group being prepared for the Differential Thermal Analysis Monograph, a large amount of work has been carried out. A study of the occurrence of a d.t.a. peak between 500° and 600° C. with these minerals has resulted in the recognition that peak temperature is only partly governed by mineralogical composition. The organic complexes of montmorillonite have also been investigated by d.t.a., and the close similarity between the resultant diagrams and those obtained with water and montmorillonite have been striking. A method has been developed for distinguishing cases of chemical from purely physical sorption. (R. Greene-Kelly.)

Study of the Clay-with-flints

The material called Clay-with-flints is a very variable deposit. In collaboration with Mr. Avery of the Soil Survey a detailed study of a series of soil profiles developed on this material at Great Hampden, Bucks., has been started with the aim of obtaining an understanding of the soils found on it and also if possible of the origin of the various materials composing it. (G. Brown and D. H. Ya'alon.)

Techniques and methods

An important factor in determining resolution in the Debye–Scherrer powder method is the thickness of the specimen. A method has been devised, using gum arabic as a binder, to make very narrow specimens. A slurry of gum arabic (10 per cent) and the powder to be photographed is made and allowed to dry on a glass slide. From this aggregate, specimens of approximately square cross-section, 0·1 × 0·1 mm. or less, are cut with a razor blade. By rotating the specimen, effects of preferred orientation are overcome. With an ordinary 9-cm.-diameter non-focusing camera, lines whose θ's differ by less than 15 minutes can be resolved, a resolution which compares

well with the results obtained with larger cameras of a semi-focusing type. (G. Brown.)

Work on the experimental gas X-ray tube, mentioned in the Annual Report for 1953, has been continued intermittently. Early in the year it was decided to consolidate the advances made and to place the experimental model in a state of ready availability for practical use. The flexible design of the set was retained, and it has been possible to carry on further researches in an attempt to improve its performance. Though the overall output of the gas set has been improved, efforts to establish a controlled focus have not been as successful as was hoped for. Focal areas of the order of 1 cm. by 1·5 mm. have been obtained by the use of shaped liners placed inside the tube, in some cases without any appreciable diminution of intensity. It has been found, however, that when designed so as to be most effective in focusing the electron stream, the liners are subject to intense bombardment by electrons, causing those made of aluminium and copper to melt, while one containing molybdenum parts began to disintegrate and rendered the tube unusable.

At the same time as the work on focal dimensions was being carried out, a 9-cm. focusing camera based on the Bragg–Brentano principle was constructed in an experimental form. With this camera it is possible in 5 minutes to obtain a well-exposed photograph from a soil clay on the new set. These photographs do not usually contain a full picture such as might be obtained from a flake or powder specimen, since focusing is only effective over a limited angle; but if certain lines only are required, these can be obtained by correct setting of the specimen. A flake specimen on the same set would require about 90 minutes to provide an equally well-exposed photograph. By using suitable shutters on the focusing camera and re-setting the specimen for each shutter, it is possible in three or four settings of 5 minutes each to obtain a complete picture in 20 minutes, as against the 90 minutes in the ordinary 9-cm. camera. The resolution of the lines obtained with the focusing camera can be controlled by altering the width of the collimating slit, greater resolution requiring longer exposures. Over a limited range and with exposures of 10–15 minutes, a resolution slightly better than that obtained with a powder camera is possible, though specimen size is an important factor. The focusing camera can therefore be used for a rough but rapid identification of a material or as a means of quickly examining a few selected lines with some accuracy.

Focusing cameras of the kind described, if they are to possess good resolving power, require a divergent beam of X-rays emanating from a line source 1 mm. or less in width. It was in order to obtain this line source that work on the focal dimensions of the gas set was undertaken. Though these efforts have not been entirely successful, it is thought that further work in this direction might be worth while.

About the middle of the year, the four-window gas set designed by D. M. C. MacEwan and made in 1951 became unusable, and examination showed that the polythene insulator had become badly damaged by bombardment with ions or electrons during use. The opportunity was therefore taken to fit to this set a completely new tube based on the design of the experimental model previously

referred to, using a porcelain insulator. One or two minor modifications were made at the same time and the general lay-out simplified. This new gas tube is now in service with an increased output of X-rays.

An important feature of both the gas tubes now in use is the ease with which they can be dismantled for cleaning or inspection, so that developing troubles can be dealt with before they become really serious. On re-assembly of the tubes, only minor adjustment of individual cameras is necessary, as the target itself can be moved so as to bring all cameras into alignment at the same time. (G. C. Dibley.)

Reaction of molten salts and micas

An investigation has been carried out of the reactions between molten salts and micas. A preliminary note giving some of the results has appeared in *Nature*. (Prof. J. L. White.)

Spectrography

Solution spark method

Work has gone forward during the year in developing the porous-cup technique of spectrographic analysis. This method of analysing solutions was first described in 1948, and has since been fairly widely developed in trace-element work on rocks and soils and in metallurgy. The source of excitation is a 10,000-volt spark, which jumps in a 2-mm. gap between carbon electrodes, of which the upper one is in the form of a cup. The base of the cup is cut to a thickness of 0·5–0·6 mm., and when once wetted is sufficiently porous to allow a slightly acid solution to percolate when struck by the spark. The medium spectrograph is used with this technique.

The method is more suitable for solutions, e.g., soil extracts, than for solids, as inevitable dilution occurs when the latter are dissolved. There are also indications that high concentrations of alkali salts cause difficulties. Nevertheless, the method is highly sensitive, and magnesium can be read at 0·05 p.p.m. with a 30-second burn.

The A.C. spark is much more stable than the D.C. arc, and results within a standard deviation of ± 3 per cent seem to be well within the possibilities of the method.

At present, working curves are available for magnesium, using the method developed by Dr. R. O. Scott at the Macaulay Institute, and the method will replace Lundegårdh determinations for Mg in routine analysis. Methods are being developed for other major elements to be used in a rapid silicate analysis of small samples. It is also hoped to use it for determination of boron, zinc and copper, all of which are possible by the porous-cup technique and are generally difficult in the D.C. arc. It is hoped that this technique, together with the use of a recently acquired flame photometer, will largely supersede the Lundegårdh method, with a consequent appreciable saving of time. (H. H. Le Riche and A. H. Weir.)

Early in the year a large number of analyses were done for the Botany Department to determine molybdenum and vanadium in plant ashes in connection with Katherine Warington's plant-nutrition work. Subsequent to this, a new technique, permitting greater

speed in such determinations, has been adopted, and applied to the analysis of plant ash for copper, iron, manganese and aluminium. It can also be used for most other elements occurring at more than about 20 p.p.m., with the exception of zinc and boron. (H. H. Le Riche.)

Geochemical studies

Pressure of other work and staff difficulties have hampered work on the study of trace-element distribution in the Lower Lias formations. A method is being used which permits the direct determination of organic carbon in these highly calcareous and pyritic materials, and evidence so far suggests that the correlation previously reported between the content of Mo, V, Ni and Cu and that of material oxidizable by the dichromate wet oxidation method is, in fact, a correlation with the organic carbon content and not that of sulphur. Further work is now proceeding on this subject. (H. H. Le Riche.)

Numerous soils from Wales were analysed as part of the programme for determining the general distribution of minor elements in soils from Great Britain. Arsenic increased by a factor of $1\frac{1}{2}$–2 from the C to A horizon, but the average for the surface samples (about 7 p.p.m.) was decidedly lower than the average for surface samples from various soils in Lancashire (15–20 p.p.m.). (J. R. Butler.)

Soil Chemistry

Effects of leaf extracts on soil constituents

Continuing work on the soil-forming properties of leaf leachates, further evidence for the operation of an inhibiting factor in the reaction between ferric oxide and an aspen-leaf extract has been obtained. Compared with the original extract, the extent of solution-reduction of ferric oxide is decreased by dialysis through cellophane. On the other hand, if the extract is shaken repeatedly with kaolin, the effectiveness of the resulting solution is considerably enhanced. Neither of these treatments is likely to have involved any change other than the removal of certain constituents—small-molecular-weight species in the case of dialysis, and species of large molecular weight by kaolin sorption. It follows from the kaolin experiment that the sorbable compounds in the original extract exert an inhibiting effect in the overall solution–reduction process; the experiment with dialysed extract shows that the low-molecular-weight constituents are the most active in causing either or both solution and reduction.

Essentially similar results have been obtained by treating the extract with ion-exchange resins, although in this case there is a possibility of artefacts being involved. In general, substitution of NH_4^+ for other cations results in increased solution, while passing the extract through an anion-exchanger (CO_3^{2-} form), results in decreased activity.

Several constituents of aspen leaf and Scots pine needle extracts have been identified, but so far it has not been possible to relate these to the action of the extracts on ferric oxide. (C. Bloomfield.)

SOIL MICROBIOLOGY DEPARTMENT

H. G. Thornton

Miss Janet Findlater from Imperial College, London, was appointed a member of the staff in October 1954.

Dr. J. W. Millbank from University College, London, on his appointment to a post under the East African Agricultural and Forestry Research Organization, was seconded temporarily to the department by the Colonial Office from October 1954.

The following worked in the department for short periods during the year :

Dr. V. Treccani, University of Milan, 20 November 1953 until 14 May 1954.

Dr. J. Schiffmann, Agricultural Research Station, Rehovot, Israel, 24 April until 12 May 1954.

Dr. W. V. B. Sundara Rao, Indian Agricultural Research Institute, New Delhi, 26 May until 15 October 1954.

Mlle H. H. de Barjac, Institut Pasteur, Paris, 7 July until 4 August 1954.

Miss E. H. Goldie, Durham University, 17 July until 18 September 1954.

The work of the department has been concerned with the antibiotic action in soil of actinomycetes against root pathogenic fungi, with the bacterial decomposition of chlorophenoxyacetic acid herbicides and chloronaphthalene, with free-living nitrogen-fixing organisms, with problems relating to nodule bacteria and leguminous plants, and with European Foul Brood of bees.

Production by Actinomycetes of Antibiotics in Soil

The reduced activity of soil-borne plant pathogens in the presence of antagonistic organisms has often been attributed to the production of antibiotics by the latter, but little direct evidence in support of this claim has been produced. I. L. Stevenson has studied the antagonism *in vitro* and in soil between various actinomycetes and the root pathogenic fungus *Helminthosporium sativum*. The degree of antibiotic activity of these actinomycete species, tested *in vitro*, was correlated with their power to control the fungus in soil. During the past year a buried-slide technique has been used to demonstrate the effects of a number of antagonistic actinomycetes on the spores and hyphae of *H. sativum* in sterilized soil. In the presence of the actinomycetes, spores either failed to germinate or were inhibited at a point just subsequent to germination. Hyphal changes ranged from the stoppage of further mycelial development to such morphological effects as stunting, distortion or the formation of hyphal protuberances. In all cases the morphological effects were characteristic for each actinomycete and identical to the changes caused by the antibiotics of the actinomycetes in

in vitro studies. Further direct evidence of antibiotic activity in soil was obtained, using the antibiotic actinomycin and *Streptomyces antibioticus*, the organism responsible for its production. When introduced into soil, identical morphological changes are shown by *H. sativum* in the presence of either the pure antibiotic or *S. antibioticus*. But extraction of the soil containing the actinomycete yielded no antibiotic, strongly suggesting a localized antagonism due to a relatively high concentration of antibiotic in the immediate vicinity of the actinomycetes.

Decomposition of Aromatic Compounds by Soil Bacteria

A comparison of the process of naphthalene decomposition by five soil micro-organisms was undertaken by N. Walker in collaboration with G. H. Wiltshire of the Biochemistry Department and Dr. V. Treccani of the University of Milan. The organisms were of widely different types, comprising a Bacterium, three species of Pseudomonas and one of Nocardia, but nevertheless all were shown to produce naphthalene diol, salicyclic acid and cathechol as intermediate oxidation products. Washed cells of all strains were found also to oxidize 1- and 2-naphthols at suitable concentrations, but in no case were napthols detected in cultures grown on naphthalene. All the organisms were also able to attack 1-chloronaphthalene, producing chloronaphthalene diol, while the Bacterium, one of the Pseudomonads and the Nocardia were all shown to produce 3-chlorosalicylic acid. The constitution of the diol produced by the Bacterium has been established as 8-Chloro-1 : 2-dihydro-1 : 2-dihydroxy-naphthalene. The problem of the identity of the intermediate products between this diol and substituted salicyclic acids is still under investigation.

An organism capable of decomposing parachlorophenoxyacetic acid, but apparently unable to attack 2-4-dichlorophenoxyacetic acid, has been isolated by T. L. Steenson. N. Walker has found that washed cells of this organism give an oxygen uptake with parachlorophenoxyacetic acid and also with 2-hydroxy-4-chlorophenoxyacetic. This supports the suggested pathway of decomposition proposed by W. C. Evans and B. S. W. Smith.

The decomposition of 2·4.D. by a strain of *Flavobacterium aquabile*, isolated from soil, has been further studied. In the presence of washed cells, eleven atoms of oxygen were absorbed per molecule of 2·4.D., but no oxygen uptakes have been obtained either with 2-hydroxy-4-chloro-, or with 6-hydroxy-2 : 4-dichlorophenoxyacetic acid, as substrates. These are thus unlikely to be intermediates in the breakdown of 2·4.D.

Free-Living Nitrogen-Fixing Bacteria

Plots on Broadbalk show very striking differences in yield of wheat in response to fallowing, and it has been suggested that these are connected with the development of nitrogen-fixing bacteria during the fallow period. Accordingly, Jane Meiklejohn has begun a series of periodical counts of these organisms from plots 3, 5, 7, 10, 17 and 18, comparing the fallow section with that longest under wheat. After harvest, high counts both of Azotobacter and of anaerobic Clostridia were obtained, but a drop in numbers of both

groups followed ploughing. This survey is being continued, and in connection with it an attempt is being made to improve existing methods of counting nitrogen-fixing organisms.

A study is also being made of the acid-tolerant nitrogen-fixing organism Beijerinckia that is found in tropical soils. The strain studied, which was isolated from soil from Tanganyika, will grow and fix nitrogen actively in a medium to which no calcium has been added. At the same time it can be adapted to tolerate calcium by growth in a calcium-rich medium. A further study is being made of the adaptability of nitrogen-fixing organisms to different levels of acidity and calcium content.

Clover Nodule Bacteria (Rhizobium)

Previous work has shown that some strains of clover Rhizobium, initially effective in fixing nitrogen, develop ineffective variant forms when grown in pure culture in certain soils. This effect of soil is clearly of importance to the practice of seed inoculation, owing to the possible danger that an effective culture used to inoculate seed may become ineffective when introduced into soil. Preliminary trials suggested that the appearance of these ineffective variants was related to soil acidity. In the past year Janina Kleczkowska has studied the behaviour of a number of effective strains of clover Rhizobium when grown in liquid and agar media, and in sterilized soil samples from the Woburn plots, the media and soil samples having reactions covering a range of from pH 4·5 to pH 7·5. All the strains tested grew on agar over the whole pH range, but in liquid medium and in soil, only one strain, found originally in an acid turf soil, survived at pH 5·0 or less.

After six months storage the cultures were plated, and colonies chosen at random were tested on the host plant. Two types of bacterial variants were found to have developed, those that no longer produced nodules at all and those that produced ineffective nodules. A higher proportion of variants appeared from agar than from soil cultures, but no correlation was found between the pH of the soil or agar medium and the number of variants. There were also big differences as between different bacterial strains in the percentage of variants produced, so that it should be possible to select genetically stable strains of Rhizobium unlikely to produce ineffective variants in soil.

Rhizobium bacteriophage

Janina Kleczkowska and A. Kleczkowski (Plant Pathology Department) have further investigated the action of ribonuclease and of chymotrypsin in arresting phage multiplication in the presence of the host Rhizobium. Earlier work had suggested that ribonuclease prevented the attachment of phage to the bacterial cell. Further investigation, however, has indicated that this substance does not prevent attachment of the phage, but makes this transitory, the attached phage being quickly released again in a free, active condition. Chymotrypsin is not able to attack free phage, but in the presence of both ribonuclease and chymotrypsin the transitory attachment of the phage is sufficient to allow the chymo-

trypsin to inactivate it. The mechanism of this inactivation, however, is not yet clear.

European Foul Brood of the honeybee

During the year F. A. Skinner has collaborated with the Bee Department in an attempt to establish the identity of the organism responsible for this disease. Professor L. P. Garrod, Pathology Department, St. Bartholomew's Hospital, London, also kindly assisted in this work by isolating from diseased larvae a small gram-positive organism morphologically resembling the type of cells that predominate in infected larval gut, and to which the name *Bacillus pluton* has been given. F. A. Skinner isolated a second organism of similar morphology. These isolates were tested by L. Bailey (Bee Department), and have so far failed to produce the disease when fed to hand-reared larvae, but the cultures are being maintained for further tests. Meanwhile the use by F. A. Skinner of new media having a high concentration of honey revealed a more diverse bacterial flora in the gut of diseased larvae. Several isolates resembling *B. pluton* have been obtained on these media and are being maintained for testing on larvae in the spring.

BOTANY DEPARTMENT

D. J. Watson

D. J. Watson attended the 17th Congress of the Institut International de Recherches Betteravières at Brussels in February, as a representative of the Sugar Beet Research and Education Committee of the Ministry of Agriculture and Fisheries.

J. M. Thurston and D. J. Watson attended the 8th International Botanical Congress in Paris in July, and J. M. Thurston and K. Warington the 2nd British Weed Control Conference at Harrogate in November.

Dr. Elsa B. Kidson, of the Cawthron Institute, New Zealand, came to work in the Department for six months.

Plant Nutrition

Interaction between iron and other micronutrient elements (K. Warington)

Solution culture studies on chlorosis caused by iron deficiency, induced directly by low iron supply or indirectly by excess of a micronutrient, have been continued. In previous experiments, the severity of chlorosis caused by excess manganese was increased when sodium molybdate was given, whereas Millikan in Australia found that in some conditions ammonium molybdate had the opposite effect. The two molybdates were therefore compared in a wider range of concentration than previously (0·1–40 p.p.m. Mo) on flax, soybean and peas subjected to direct instead of manganese-induced iron deficiency.

In the early stages of growth, 40 p.p.m. Mo prevented apical chlorosis in flax when the iron supply was low, and deepened the green colour of plants with a high iron supply. The effects were greater, lasted longer and were detectable at a lower concentration (20 p.p.m.) with ammonium than with sodium molybdate. At later stages of growth, 40 p.p.m. Mo produced toxic symptoms, except in high-iron plants, restricting root growth. Similar effects were found in soybean and peas, but the mitigation of chlorosis was not so pronounced or so persistent. The divergent effects of molybdenum on chlorosis were thus shown to depend on the form and concentration of the molybdenum supplied, as well as on the nature and age of the plant, but the conditions in which molybdenum alleviates or intensifies the effects of iron deficiency cannot yet be precisely defined.

In the later stages of growth the high rate of iron supply (30 p.p.m.) was toxic to flax, but its harmful effect was reduced by 40 p.p.m. Mo. This action of molybdenum in offsetting effects of iron excess is similar to those of manganese, copper and zinc described by other workers.

Increased molybdenum supply usually reduced the iron content of the shoot, even when, at the low rate of iron supply, it decreased the severity of chlorosis. It greatly increased the iron content of the roots. High iron supply reduced the molybdenum content of

both shoot and root, except in the flax plants which showed symptoms of iron excess.

To find out whether the effect of increased iron supply in reducing toxicity due to micronutrient excess occurs inside the plant, or outside it in the nutrient solution, a toxic concentration of vanadium (2·5 p.p.m.) was given to peas and soybeans with high or low iron concentration, in the same solution or separately in successive time intervals. For peas, the reduction in the toxicity of vanadium by the high iron supply was greatest when vanadium and iron were given in the same solution, so that here the interaction occurred, at least in part, outside the plant. But with soybean the highest yields were obtained when iron was given in the initial treatment, either alone or with vanadium.

In an experiment on soybean, iron supplied as the ferric complex of disodium ethylenediamine tetracetate (Fe-EDTA) was found to be more effective in reducing vanadium toxicity than when given as ferric citrate. In the presence of low vanadium (0·1 p.p.m.) 2·5 p.p.m. Fe as Fe-EDTA gave the same dry weight yield as 20 p.p.m. Fe as citrate; plants receiving 2·5 p.p.m. Fe as citrate were chlorotic, and 20 p.p.m. Fe as Fe-EDTA was harmful and reduced the dry weight yield. With the low rate of citrate, 2·5 p.p.m. of vanadium was very injurious, but its toxicity was nearly inhibited by the low rate of Fe-EDTA or the high rate of citrate. The high rate of Fe-EDTA still produced symptoms of iron excess where vanadium was given at the high rate, but they were less severe than at the low vanadium level. Although Fe-EDTA was much more effective than citrate, it caused no greater uptake of iron, but at the lower rates of supply a larger fraction of the iron absorbed was contained in the shoot when iron was given as Fe-EDTA than when it was given as citrate.

Nutrient uptake by excised roots (E. C. Humphries)

Further investigations of factors controlling uptake of ions by excised roots, and especially of the rôle of carbohydrate, has confirmed that the positive correlation between rate of nutrient uptake and sugar content of the roots is attributable to the reducing sugar fraction, and an attempt has been made to find out whether fructose or glucose—the only reducing sugars that have been detected in barley roots—or both, are concerned. The sugar content of roots was varied by change in nitrogen supply to plants from which the roots were taken, by shading the plants or by supplying sucrose to the solution in which the excised roots were held. The effects of these treatments on the rate of potassium uptake by the excised roots, and on their content of glucose, fructose and sucrose were measured. A regression analysis of the results showed that the rate of potassium uptake increased with increase in fructose content, but decreased with increase in glucose or sucrose.

Experiments were also continued on the effect on rate of potassium uptake by low-sugar, low-salt roots of adding different sugars to the 0·01*M*-KCl solution in which the roots were held. Separate addition of either fructose, glucose or sucrose increased the uptake of potassium and the amounts of all three sugars in the roots. The increase in sugar content continued steadily throughout the absorption period. Statistical analysis of these results is not yet complete.

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The effects of sugars other than those normally present in the roots were also tested. Sorbose increased the rate of potassium absorption to about the same extent as fructose or glucose, L- and D-arabinose and L-rhamnose gave slight increases in rate of uptake, L-galactose had practically no effect, and mannose and D-glucosamine had inhibitory effects on the rate of uptake, even in low concentrations (0·1 per cent). It is not yet known whether the sugar applied accumulated as such in the roots or was converted to other forms. The results suggest that the second carbon atom of a hexose sugar is important in determining whether it acts as an inhibitor of potassium uptake.

" Cloud " or " blotchy ripening " of tomato fruits (E. B. Kidson)

The disease of tomato fruits called " cloud " in New Zealand and " blotchy ripening " in this country is thought to be a nutrient disorder, but its cause is not yet understood. Its symptoms are the persistence of green patches on ripening fruits and necrosis of the vascular tissue in the affected parts of the flesh. Its incidence is increased by soil sterilization, and as the plants then also have a high manganese content, manganese toxicity has been suggested as a possible cause. This and a number of other factors were tested in a solution-culture experiment. Though the high-manganese plants showed chlorosis of the leaves typical of manganese excess, the fruits were free from " cloud ". At an early stage of the experiment, vascular necrosis was found in fruits from plants receiving high iron supply, but not where a lower iron supply was given. However, the symptoms were not characteristic of " cloud ", and were not found in fruits that developed subsequently. Typical " cloud " symptoms appeared at a later stage of the experiment when plants were transferred to a more dilute culture solution. These experiments will be continued in New Zealand.

Nutrient uptake from leaf sprays (G. N. Thorne)

Previous attempts to account for low recovery of nutrients supplied in leaf sprays, estimated from the difference in total nutrient content between sprayed and unsprayed plants, showed that, for plants receiving a balanced nutrient supply to the roots, uptake of a nutrient from leaf spray did not reduce uptake of the same nutrient by the roots (Report of Rothamsted Experimental Station for 1953, p. 70). Experiments on swedes have now shown that such a reduction can occur when the supply to the roots of the nutrient concerned is high relative to other nutrients. When sodium phosphate solution labelled with ^{32}P was applied with a paint brush to the leaves of plants grown in a high phosphorus solution, 11 mg. P per plant were absorbed through the leaves, and phosphorus uptake by the roots was reduced by about the same amount, from 31 mg. in unpainted controls to 21 mg. in painted plants.

The results of a series of experiments in which measured volumes of ^{32}P labelled sodium phosphate solutions were carefully applied with a glass rod or paint brush to leaves of swede plants showed that 90 per cent of the phosphorus applied to the leaves was recovered either inside the plant or as an external deposit that could be washed off the leaves. The same recovery was found whether the plants were harvested immediately after treatment or after

several days, showing that no continuous loss occurred, and it is therefore concluded that the 10 per cent not recovered represents losses during digestion of the plant material and at other stages of the manipulation. None of the phosphorus absorbed by the leaves was excreted into the nutrient solution surrounding the roots, so it appears that all the phosphorus from the solution retained by the leaves either remained as an external deposit or was absorbed and partially translocated to other parts of the plant.

^{32}P was detected in the roots of small swede plants 4 hours after application of the solution to the leaves. Absorption from the dry deposit continued for 2–3 days, by which time about half the applied phosphorus had entered the plant, but there was no further uptake during the next 10 days. Trebling the concentration of the solution increased the percentage uptake of phosphorus slightly. Absorption was greater through the lower than through the upper surface of the leaf, and was not increased by spraying twice with water at daily intervals after applying the ^{32}P solution.

Some more work was done on application of nitrogen in sprays to winter wheat (Report of Rothamsted Experimental Station for 1953, p. 70). As weed-killers are often applied to wheat at about the same time as a nitrogenous spring top-dressing, one operation could be eliminated if the fertilizer could be applied in the same solution as the weed-killer without detriment to either. To test this, 0·5 cwt. N per acre as ammonium nitrate or urea was applied in mid-April to the soil, or sprayed on the crop in 30 gal. per acre of solution. Half the plots were sprayed with 2-4D, and where the fertilizer was also sprayed, the two were given in the same solution. The weed-killer was supplied, and the spraying done, by the Agricultural Research Council Unit of Experimental Agronomy, Oxford. The wheat was slightly scorched by the nitrogen spray, with or without 2-4D, but soon recovered. Unfortunately, the crop was severely affected by " take-all ", and gave a low yield, with negligible responses to either soil or spray applications of nitrogen, though the nitrogen content of grain and straw was slightly increased. Many of the weeds were of species resistant to selective weed killers, but the amount of mayweed (*Matricaria inodora*) was reduced by the 2-4D spray. The experiment will have to be repeated in conditions that provide greater responses to fertilizer and weed-killer.

Weed Studies

Wild Oats (J. M. Thurston)

In the fourth year of the field experiment testing the effect of different cultivation treatments on the survival of wild oats seeds sown at two depths in October 1950 (Report of Rothamsted Experimental Station for 1953, p. 71) germination fell to a very low level. Less than 1 per cent of the seeds of *Avena fatua* sown in 1950, and less than 0·1 per cent of *A. ludoviciana* seeds germinated. The total germination of *A. fatua* in the four years of the experiment, for the treatment that gave most seedlings, is only 20 per cent, and of *A. ludoviciana* 16 per cent. The cultivation treatments have been discontinued, and the whole area dug with a spade in March and again in September to encourage germination of surviving viable wild oats seeds and to control other weeds. The fate of the 80–90

per cent of seeds that have so far failed to produce seedings is not yet known. When seeds left over after sowing in 1950 and subsequently stored in the laboratory were tested in January 1954, 86 per cent of *A. ludoviciana* seeds and 72 per cent of *A. fatua* were still viable.

The experiment in Hoosfield comparing the effects of winter and spring cereals on the establishment and growth of *A. fatua* (Report of Rothamsted Experimental Station for 1953, p. 71) was continued. This also showed a large reduction in the number of seeds germinating; in winter rye there were 40 per cent of the number found in 1953, and on the other plots only 20 per cent. The inverse correlation found in 1953 between the number of wild oats germinating and weight of the cereal crop at the time was not apparent in the second year, but compared with fallow or spring barley the winter cereals all greatly reduced the growth of wild oats.

A pot experiment was done on competition between wild oats and cereal crops, to study the effect of the size of the crop plant at the time when the wild oats germinate on subsequent growth of the wild oats and the number and dormancy of the seeds they produce. Three sowings of spring barley and spring wheat at two rates were made at weekly intervals, and chitted seeds of *A. fatua* were planted 4 days after the last sowing of the cereal crop, in pots with and without barley or wheat. Competition with the crop reduced seed production by the wild oats; the mean numbers of seeds per plant when 3 wild oat plants were grown in pots with 0, 3 or 9 cereal plants were 748, 181 and 59 respectively. Barley (Herta) was a more effective competitor than wheat (Atle); there were only 62 seeds per plant of wild oats in the barley pots, compared with 178 in the wheat pots. Seed production by the wild oats was reduced by earlier sowing of the cereal crop; when the crop was sown 18 days before the wild oats were planted, there was an average of 71 wild oat seeds per plant, but when the interval was only 4 days there were 192 seeds per plant. This result shows that early sowing and establishment of the crop may have a useful effect in minimizing the multiplication of wild oats in spring cereals. A similar experiment has been started on competition between autumn-sown wheat, barley or rye and *A. ludoviciana*.

Variability in germination of wild oat seeds in the fluctuating temperature of a glasshouse suggested that summer temperatures induce dormancy that can be overcome by cooling and drying the seeds. This was tested in an experiment on both *A. fatua* and *A. ludoviciana* in which imbibed seeds were held in warm (27° C.) or cool (5–10° C.) conditions, or alternated between the two in 2-daily intervals. Half the seeds were pricked to break seed-coat dormancy. After 7–9 weeks, when germination had ceased, the ungerminated seeds were all transferred to cool conditions and allowed to dry. They were then re-moistened and held at 5–10° C. for a further six weeks, until germination stopped again.

The total germination of the pricked seeds up to the end of the final low-temperature exposure was taken as a measure of viability. Exposure to warm conditions reduced the viability of *A. fatua* seeds to 48 per cent, and the alternating temperature to 80 per cent, compared with 93 per cent for those held in cool conditions throughout. The numbers of dormant seeds at the end of the experiment,

determined from the differences between the total germinations of pricked and unpricked seeds, amounted to 66 per cent of the viable seeds, for those held in cool conditions throughout. Warm conditions, whether continuous or alternating, increased the percentage of viable seeds that were dormant to 90 per cent. No conclusions could be drawn from *A. ludoviciana*, because more unpricked seeds germinated than pricked seeds after exposure to the higher temperature, possibly because pricking led to infection and death of many seeds, but it appears that there was little residual dormancy in *A. ludoviciana* whatever the treatment in the first period. Another experiment showed that the inhibition of germination of *A. ludoviciana* seeds at 27° C. could not be overcome by drying and re-wetting the seeds, but only by cooling them.

Removal of part of the panicles, as might occur if attempts were made to control wild oats by cutting off the inflorescences above the cereal crop before the emergence of the cereal ears (Report of Rothamsted Experimental Station for 1953, p. 72), had no effect on the dormancy of the remaining seeds of *A. fatua*, but increased the percentage of first seeds of *A. ludoviciana* germinating within 10 weeks of sowing. The proportion of second seeds of the spikelets of *A. ludoviciana* that are dormant in the first year after they are produced is normally higher than of first seeds, but when the first seeds were removed at an early stage of their development, it was found that dormancy in the second seeds was reduced to about the same percentage as of first seeds in intact spikelets.

Two experiments on the survival of wild oat seeds under a grazed temporary ley have been started, one in collaboration with the National Agricultural Advisory Service at Boxworth Experimental Husbandry Farm, and the other on a commercial farm.

Other weeds (J. M. Thurston)

In an experiment at Woburn, the effects of autumn-sown and spring-sown cereals on the weed flora were investigated by comparing plots sown in autumn with rye or barley, or in spring with barley or wheat, or fallowed with cultivation as for an autumn-sown or spring-sown crop. Rye was the heaviest crop, and appeared to be almost free from weeds compared with fallow or the much lighter spring cereal crops, which were very weedy. The difference was wholly due to the size of the weed plants, for they were just as numerous on the rye plots as on the others. This illustrates the importance of growing good crops in helping to control weed infestation. *Matricaria inodora*, the most abundant weed species, and *Polygonum aviculare* were almost confined to autumn-cultivated plots. The numbers of plants of these species did not vary with crop or fallow. *Polygonum convolvulus*, on the other hand, was equally frequent on autumn- and spring-cultivated plots, but there were fewer plants in autumn rye than barley, and they were most abundant in spring barley. *Spergula arvensis* also germinated in spring, and was present on plots of all treatments, but was most abundant on spring-cultivated plots. In June there were fewer spurrey seedlings on fallow plots cultivated in spring than in the spring-sown crops, suggesting that the presence of the crop stimulated the germination of spurrey seeds, but later this difference disappeared.

In all, twenty-eight weed species were present and fourteen of these were sufficiently abundant to be recorded separately, but the results for all of them are not yet analysed.

Physiological Effects of Virus Infection

Effect of infection with tobacco mosaic virus on the respiration rate of tobacco leaves (P. C. Owen)

Three weeks after tobacco plants were infected with tobacco mosaic virus, when symptoms of systemic infection had appeared, the respiration rate of older leaves in the 20 hours after they were detached, expressed as CO_2 per g. dry matter, was found to be the same as that of comparable leaves from healthy plants. The respiration rate of younger leaves from infected plants was about 10 per cent less than that of comparable healthy leaves. These effects were independent of seasonal change in light conditions during the growth of the plant. The reduction in respiration rate of the younger leaves by infection persisted throughout the 20-hour period of measurement, though it decreased during the first 5 hours, when the respiration rate of both healthy and infected leaves was rapidly falling. This initial fall is presumably caused by decreasing supply of carbohydrate substrate, and the persistence of the effect of infection into the stage when respiration rate has fallen to nearly steady values suggests that infection reduces the activity of the oxidative mechanism, and not merely the substrate supply.

The initial water content of the older leaves, but not the younger leaves, of infected plants was less than that of comparable healthy leaves, and all the infected leaves absorbed less water than the healthy leaves during the experimental period. The effects of TMV infection on water content were so large that the rate of CO_2 production per g. fresh weight was sometimes significantly increased by infection.

The results of these experiments and some reported previously (Report of Rothamsted Experimental Station for 1953, p. 73) (55, 56) show that the respiration rate of TMV-infected tobacco leaves can be higher or lower than, or identical with, that of healthy leaves, depending upon the time elapsed after inoculation, the environmental conditions during growth, the age of the plants and stage of development of the selected leaves, and the basis of expression of the results. This presumably explains the contradictory statements in the literature on the way TMV affects respiration, and shows the importance of defining these factors in any future work.

So far, the effects of TMV-infection have been measured immediately after inoculation, and after the development of systemic infection. Experiments are now in progress on the intervening period, during which virus is multiplying in the plant.

Growth Analysis

Effect on sugar beet of infection with beet yellows virus (D. J. Watson and P. C. Owen)

The automatic gas-sampling unit used in connection with an infra-red gas analyser to make intermittent measurements of the CO_2 concentration in four gas circuits (Report of Rothamsted

Experimental Station for 1953, p. 73) was reconstructed to work at higher flow rates. It was used to measure the diurnal CO_2 exchange of whole sugar-beet plants grown in sand culture from the time when they were infected with beet yellows virus until symptoms appeared, and in a subsequent period when infection was well established. Similar measurements were made on healthy plants. At the beginning and end of both periods samples of infected and healthy plants were taken for measurements of total dry weight and leaf area. This will enable net assimilation rates, calculated from dry-weight increments and leaf areas, to be compared with direct measurements of CO_2 uptake during the day and CO_2 loss at night, so that the extent to which the reduction is net assimilation rate caused by infection (Report of Rothamsted Experimental Station for 1952, p. 73) is attributable to decreased photosynthetic gain or increased respiratory loss of dry matter can be determined. The results are not yet all worked out.

Effect of time of application of nitrogenous fertilizer and of mildew infection on the yield of wheat (G. N. Thorne and F. T. Last, Plant Pathology Department)

The primary object of this experiment was to measure the effect of infection with mildew (*Erysiphe graminis*) on the yield of winter wheat. The development of mildew infection is correlated with leaf-growth rate, so it can be varied at different stages of growth by varying the time of application of nitrogenous fertilizer (Report of Rothamsted Exp. Sta. for 1952, p. 92; 1953, p. 93). Many experiments have shown that, apart from short-period weather effects, the response to nitrogenous fertilizer in grain yield of wheat is independent of time of application over a wide range, but the response in straw yield decreases steadily with later application. A second object of the experiment was to investigate the physiological mechanism of this constancy in response of grain yield.

Wheat was grown in soil in pots, and received either no nitrogenous fertilizer or nitrogen applied soon after germination in November, or as a top dressing in April, or at ear emergence in mid-June. Half the pots of each nitrogen treatment were inoculated with mildew spores, and the rest were kept free from mildew by repeated spraying with lime sulphur. At regular intervals pots were sampled for determination of dry weight, leaf area, shoot number, etc., according to the usual growth-analysis procedure, and the intensity of mildew infection was assessed. The dry matter that enters the grain is all produced after ear emergence by photosynthesis, mainly in the flag leaf and its sheath, the stem and the ear. Records were therefore made of the size and longevity of the flag leaves, and the contribution of the ears was measured by shading the ears in half the pots with opaque paper tubes immediately after they emerged so as to prevent them photosynthesizing. The reduction in dry weight caused by the shading gave an estimate of photosynthesis in the unshaded ears. Analysis of the data from this experiment is not yet completed. Contrary to previous experience, the nitrogen application at ear emergence had little effect on grain yield, though the earlier applications caused large increases; the reason for this is not known, and needs further investigation.

Dependence of net assimilation rate on leaf area index (D. J. Watson)

Last year it was reported (Report of Rothamsted Experimental Station for 1953, p. 73) that when leaf-area index (L; ratio of leaf area to land area) of a kale crop was greater than about 2·5, the crowding together of the leaves caused mutual interference in their photosynthesis, and the net assimilation rate (E) was reduced. A more detailed investigation, in which L was varied, as previously, by removing at the beginning of successive 10-daily periods different fractions (usually 0, $\frac{1}{4}$, $\frac{1}{2}$ or $\frac{3}{4}$) of the plant population on different plots, has now shown that E decreased almost linearly with increase of L, so that when L = 5, E was reduced to about a quarter of its value when L = 1. Consequently, the rate of dry-matter production per unit area of land reached a maximum when L was between 3 and 4, and decreased when L was increased to higher values. Close spacing, heavy fertilizer application and frequent rain combined to give a very heavy crop, which, on the unthinned plots, produced a yield of over 6 tons acre of dry matter at the end of September. The leaf area index of the unthinned crop was greater than 4 from the beginning of July onwards, so that during the most productive part of its growth, the crop had too great a leaf area for maximal dry-matter production. This implies that an even greater total yield of dry matter might have been obtained by repeated thinning of the plants or removal of leaves from each plant, to maintain L at about the optimal value between 3 and 4. The position of the maximum rate of dry-matter production was independent of the seasonal drift in net assimilation rate. It occurred at the same value of L in July, when E (for L = 1 approx.) was over 50 g. m.^{2} week, as in September, when E was about 30 g. m.^{2} week.

Measurements made in the same way on sugar beet showed that when L increased from 1 to 5, E was reduced by less than 25 per cent, compared with 75 per cent for kale. Consequently, the rate of dry-matter production per unit area of land increased throughout the whole range of E, and the highest value of L attained by the sugar-beet crop, about 6, was still below the optimum for dry-matter production.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

Margaret Holden has been seconded to the West African Cocoa Research Institute, to study the composition and metabolism of normal cocoa leaves and leaves from plants with Swollen Shoot.

W. R. Smithies resigned and W. S. Pierpoint joined the department.

N. W. Pirie attended a symposium on " Solar Energy and Wind Power " organized by UNESCO and the Indian Government in New Delhi in October.

The Influence of Light on the Resistance of French-bean Leaves to Infection with Tobacco Necrosis Virus

(G. H. Wiltshire)

The study of the changes in concentration of organic acids in French-bean leaves has been extended to malic and citric acids. The latter, at about 0·02*M* concentration, is known to reduce infectivity of TNV when mixed with the virus *in vitro*.

Several methods for the extraction and estimation of these acids have been tried. Approximate results could be obtained by analysis of an ether extract of heat-dried leaf, but heat converted some of the malic to malonic and acetic acids, which were not present in the unheated leaf. The procedure eventually adopted includes aqueous extraction of leaves previously ground to a powder while frozen at —20°, purification of the extract on ion-exchange resins and partition chromatography of the acids on silica gel. Acids titrated in successive fractions of the eluate were identified by chromatography on paper.

Under normal greenhouse conditions in June, leaves contained about 3·9 m.equiv. of malic and 2·6 m.equiv. of citric acid per 100 g. fresh weight. In October the values were 2·9 and 2·6 respectively. The total organic acid content (of which malic and citric acids make up about 70 per cent) fell by 17 per cent in plants placed in the dark for 3 days in June. Nearly half the malic acid was lost, while the citric increased by about 15 per cent.

Leaves detached from the plant 2 days before inoculation and floated in water produced less lesions than leaves left on the plant; the reduction may be attributed to dilution of the inoculum with water. Otherwise these leaves behaved usually like attached leaves, producing more lesions if kept in the dark before inoculation, though sometimes there was no increase. Leaves floated in 0·003*M* solutions of malate or citrate, then washed before inoculation, produced fewer lesions than those in water but more than those in 0·03*M* malate or citrate. Potassium malonate had the same effect as malate and citrate. It is not yet known whether the infiltrated acids accumulate or are metabolized by the leaf. Since infiltration with these acids decreased lesion number equally in the light and in the dark, it is unlikely that resistance to infection depends simply on the concentration of any one of them.

A decrease in resistance to infection similar to that produced by darkening was found in plants kept in the light but deprived of carbon dioxide. Both treatments prevent photosynthesis, and may thus make the leaf more easily infected in the same way.

Plant Enzymes Catalysing Oxidations

(R. H. Kenten)

This year, work has been started on the enzymatic constitution of the bracken plant, and shortly, studies of the effect of certain mineral deficiencies on the enzymes of plants will be undertaken. It is hoped that these researches may lead to the formulation of a bracken-killing agent on the one hand and the development of biochemical tests for mineral deficiencies on the other. The work involves the demonstration and estimation of enzyme activities of plants. Unknown factors which affect the activities of the plant enzymes during their extraction or assay can vitiate such studies. It is for this reason that a study of broad-bean-leaf polyphenol oxidase has been undertaken. By analogy with the known phenol oxidases it is most likely that the broad-bean enzyme is a Cu-protein.

Polyphenol oxidase

Water extracts of broad-bean leaves when assayed at pH 6–7, in the usual way, for polyphenol oxidase often show little or no activity. Prolonged incubation (48 hours) of such extracts at 37° (in the presence of toluene) leads to an increase in activity. When the extract is incubated in the presence of certain proteolytic enzymes (e.g. trypsin) large increases in activity are obtained in a short time (1–2 hours), but if incubation is prolonged (48 hours) the activity is largely destroyed. Large increases in the polyphenol oxidase activity of the leaf extracts can be brought about instantaneously by treatment with certain anionic wetting agents (e.g., sodium dodecyl sulphate) or by acidification to pH 4. Inactive leaf extracts show no increase in activity after dialysis for 48 hours at 0°, but the treatments described above bring about large increases in the activity of dialysed extracts. The nature of these phenomena is not yet clear, but, since all of the treatments which result in an increase of activity can also lead to protein denaturation or degradation, the hypothesis is advanced that at the normal pH of the sap (about pH 6) the polyphenol oxidase is largely present in the form of a complex with another protein or large peptide which prevents it exerting its normal catalytic function. Whether such complexes are present *in vivo* or are formed by protein interaction during the preparation of the leaf extract is not known. A knowledge of these phenomena, apart from its importance in plant-enzyme studies, may help in the elucidation of the activation and inactivation processes which sometimes accompany the extraction and purification of plant viruses.

Enzymes of bracken

Studies have been made of the peroxidase, catalase and polyphenol oxidase activities of the bracken plant at various stages of growth. With the exception of peroxidase, which may be absent in the mature leaf, all three enzymes were found in the rhizome,

stem and leaf throughout the year. Large differences were found in the catalase and polyphenol oxidase activities of the different plant parts, and in the leaf these activities varied greatly with age. The growing portions of the plant (frond bud, young leaf, rhizome tip) had the highest polyphenol oxidase activities. For example, the activities of the frond bud or young leaf were some 60–300 times greater than that of the rhizome and about 20 times that of old leaf. On the other hand, while the growing portions had a higher catalase activity than that of the rhizome, the highest activity was found in the fully expanded leaf. Peroxidase activity was very low in all of the samples examined.

Manganese Oxidation by Illuminated Chloroplast Preparations

(R. H. Kenten and P. J. G. Mann)

It has been suggested that a manganese oxidation–reduction cycle may be concerned in the reactions of photosynthesis. We have previously found, in preliminary experiments, that added Mn^{++} is oxidized by illuminated chloroplast preparations. This reaction has been further investigated in view of its possible physiological significance.

Two methods have been used to follow the oxidation. At high concentrations of Mn^{++} the oxidation product can be estimated manometrically by measuring the N_2 output on addition of hydrazine. At physiological concentrations of Mn^{++} the manometric method is not sufficiently sensitive, and a spectrophotometric method has been evolved which is suitable for estimating Mn^{++} at a concentration of 2–7 μg./ml. Using these methods, it has been shown that the oxidation proceeds at physiological concentrations of Mn^{++} and depends on the intensity of illumination and the amount of chlorophyll present in the chloroplast preparations. Oxidation proceeds to about the same extent in both pyrophosphate and orthophosphate buffers. In pyrophosphate the oxidation product accumulates as soluble manganipyrophosphate, but in orthophosphate the oxidation product is insoluble. Like MnO_2, it can be dissolved by treatment with pyrophosphate containing Mn^{++} to give manganipyrophosphate, but it differs from hydrated MnO_2 in that it reacts much more slowly with hydrazine in the manometric method of estimation, though finally giving a greater total N_2 output. It is of interest that we obtained a similar oxidation product in previous work in which the oxidation of Mn^{++} was brought about by coupling enzyme systems producing H_2O_2 with peroxidase systems in orthophosphate media.

The mechanism of the oxidation of Mn^{++} by illuminated chloroplast preparations has not been completely elucidated. A thermolabile factor is involved, added catalase partially inhibits the oxidation, while added peroxidase increases the rate of oxidation, though the amount required to produce a significant increase is large in comparison with that present in the chloroplast preparations. These results, in conjunction with our previous results on the oxidation of Mn^{++} by peroxidase systems, suggest that, at least in part, the oxidation is due to peroxidase systems.

Plant Amine Oxidase and Some Reactions it Catalyses

(P. J. G. Mann)

The study of the products formed as a result of the oxidation of putrescine, cadaverine, lysine and *o*-amino-β-phenylethylamine catalysed by plant amine oxidase has now been completed, and the work has been prepared for publication. These oxidations all produce heterocyclic compounds and, when putrescine and cadaverine are the substrates, the products are key substances in model syntheses of pyrrolidine and piperidine alkaloids. The results therefore support the suggestion that the enzyme may be concerned in the synthesis of alkaloids. From reaction mixtures with DL-lysine as substrate, following catalytic hydrogenation, the 2 : 4-dinitrophenyl derivative of DL-pipecolinic acid has been isolated. The fact that the enzyme catalyses the oxidation of both L- and D-lysine, previously suggested from observations with L- and DL-lysine as substrate, has been established thanks to a gift of D-lysine from Dr. J. P. Greenstein. From reaction mixtures with cadaverine as substrate *iso*tripiperideine, a polymer of Δ′-piperideine, has been isolated. One of the main products of the hydrogenation of *iso*-tripiperideine is 2 : 3-dipiperidine. The latter compound is a derivative of the alkaloid anabasine, which is isomeric with nicotine. Indole has been isolated after the enzyme-catalysed oxidation of *o*-amino-β-phenylethylamine in 90 per cent yield. During the course of this work it has been shown that peroxidase catalyses the oxidation of indole by hydrogen peroxide.

In some plants tryptamine can function as a precursor of 3-indolylacetic acid. We have previously shown that the oxidation of tryptamine is catalysed by plant amine oxidase, and have suggested that the reaction product would be 3-indolylacetaldehyde, which, on further oxidation, catalysed by aldehyde oxidase, would give 3-indolylacetic acid. Other workers have obtained evidence of the presence of 3-indolylacetaldehyde in plants as "neutral auxin" and of its conversion to 3-indolylacetic acid by plant tissues. We attributed our previous failure to isolate 3-indolylacetaldehyde as the product of the amine oxidase-catalysed reaction to the fact that, in the crude preparations of amine oxidase then used, other enzymes were present which catalysed the oxidation of the product of the primary reaction. With the highly purified enzyme preparations now available it should be a relatively simple matter to find out whether the aldehyde is the product of the oxidation of tryptamine, and experiments to test this have been started in view of the possible significance of the reaction *in vivo* and in the hope that the reaction may prove to be a simple method of preparing the aldehyde. In the presence of catalase, purified amine oxidase gives a quick O_2 uptake until 0·5 mol. O_2 has been taken up and 0·5 mol. NH_3 formed for each mol. of tryptamine. Thereafter the O_2 uptake is slow. No CO_2 is formed during the reaction, and colorimetric tests suggest that the indole ring remains intact in the oxidation product. From the reaction mixture a 2 : 4-dinitrophenylhydrazone and a dimedone derivative have been isolated in yields of 20–30 per cent, suggesting that a carbonyl compound, probably an aldehyde, is one of the main products. In both cases

the melting points are only slightly lower than those recorded for the corresponding derivatives of 3-indolylacetaldehyde. Further oxidation of the reaction products with silver oxide results in the formation of a compound resembling 3-indolylacetic acid in colorimetric tests and in investigations by paper chromatography.

We have shown previously that hydrogen peroxide is formed in the reactions catalysed by plant amine oxidase. This is a characteristic of flavoprotein enzymes, but attempts made in the present work to demonstrate that a flavin is the prosthetic group of the enzyme have so far been unsuccessful. Evidence has, however, been obtained that a metal may form a part of the prosthetic group. Thus the enzyme is inhibited by sodium diethyldithiocarbamate, potassium ethyl xanthate and salicylaldoxime, which are usually considered as specific inhibitors of copper-containing enzymes. In preliminary experiments the three plant amine oxidase preparations so far examined for heavy metals have been found to contain 0·05–0·06 per cent copper and 0·03–0·04 per cent manganese based on the protein content. No proof has yet been obtained that the presence of either of these metals is essential for the activity of the enzyme.

Properties of Fractions from Leaves Infected with Tobacco Mosaic Virus

(N. W. Pirie)

Measurements have been made of the amount of antigen, reacting specifically with anti-TMV serum, in the supernatant fluids and pellets after centrifuging extracts of infected leaves at 30,000–60,000 g. The ratio between the two types of antigen varies with the strain of virus used, the age of the inoculated plant, the duration of infection and the cultural conditions, but we never find more than one-tenth of the whole in the unsedimented fraction.

After various treatments, such as heating to 60° and incubation with proteolytic enzymes, the unsedimented material aggregates and then sediments normally. Neither in the native nor aggregated state does it carry an amount of infectivity larger than could be explained by contamination. Similar material has been made in other laboratories, and there are claims that it is free from P and so from nucleic acid. Some of our preparations have a lower P content (0·2 per cent instead of 0·5 per cent) than that characteristic of the sedimentable fraction, but we have not encountered a serologically active fraction free from P.

TMV preparations made by ultracentrifugation carry several enzyme activities and P in states of combination other than firmly bound ribonucleic acid. The obvious interpretation is that this is a consequence of contamination, but other interpretations are being explored (with F. C. Bawden).

Leaf Ribonuclease and Nucleoprotein

(M. Holden and N. W. Pirie)

Preparations of leaf ribonuclease have now been got sufficiently free from phosphomonoesterase, phosphodiesterase, deoxyribonuclease and some other enzymes for it to be clear that the enzyme is relatively specific. Our best preparations, however, still carry

activity against metaphosphate and adenosine triphosphate.* These preparations are as active, weight for weight, as the most highly purified preparations from pancreas, but they are still inhomogeneous.

Improvements have been made in the methods used to prepare nucleic acid from yeast, viruses and normal leaf nucleoprotein and, using these less contaminated preparations as substrates, we have been able to systematize our observations on the kinetics of ribonuclease action. The outstanding differences between enzyme from leaf and pancreas are that the former, as stated in earlier reports, carries hydrolysis farther than the latter and that it is more easily inhibited by several inhibitors. Some of these inhibitors, notably Ca, Mg and Zn, are present in the particles of normal leaf nucleoprotein, and this probably explains some of the anomalies in its behaviour *in vitro*.

Large-Scale Production of Leaf Protein

(D. Fairclough and N. W. Pirie)

Effort has still to be directed more to perfecting machinery than to measuring its performance in use. The pulper, which is the first machine to have been built expressly for this job, works well, and on any material that is worth using we can grind up to 1 ton per hour for the expenditure of 25 H.P. To get good performance, steady even feeding is necessary, and we have perfected an automatic feeder which can be loaded intermittently, but, by a system of relays controlled by the current taken by the driving motor of the pulper, maintains a feed that keeps the pulper working optimally.

The adequacy of pulping is assessed in three ways: by measuring the total amount of protein liberated from the fibre; by measuring the rate at which juice is expressed under standard conditions of pressing; and by measuring the yield of protein that can be attained in practice. Laboratory-scale equipment has been built for the first two operations and a full-scale press for the last.

This press is the first of its type, and in it a piston presses the pulp on a perforated conveyor which is only moved forward between the piston strokes. It runs automatically, and the intensity and duration of pressure are adjustable. We are still measuring the performance of this press with different thicknesses of pulped material on the belt so as to find what increase in juice expression is got by diminishing the rate of working. The press has also been used on grass that has not been pulped but simply exposed to steam sufficiently to destroy osmotic control in the leaf cells. From steamed leaves, unlike raw leaves, it is easy to press two-thirds of the water with a variable but small loss of sugars, amides, etc. In dried grass manufacture it may well be that, in spite of this loss, it would be more economical to press out water rather than to dry it off.

Our technique for handling the protein-containing juice coming from the press and for processing the protein is still relatively crude, and the possibilities of improving it are being actively explored. In agreement with earlier work, both in the laboratory and on a

* Pierpoint has now removed these two activities from the preparation.

large scale (cf. " Large-Scale Production of Edible Protein from Fresh Leaves " in *Report of the Rothamsted Experimental Station for 1952*), we find that from leaves containing more than 18 per cent of protein it is easy to get 30–40 per cent of the protein in one extraction and up to 60 per cent by two extractions.

The Properties of the Resistant Parts of Fungal Mycelium which May Accumulate in Soils

(M. V. Tracey)

It has previously been reported that the mycelium of a number of soil fungi cannot be broken down completely by the enzymes that have so far been investigated. In part this appears to be due to the protection of a varying amount of the chitin that they contain from attack by chitinase. The chitin of the mycelium of the mature puffball is completely resistant to enzymic attack, and it has therefore been used as a suitable material for further study. Efforts were made to isolate micro-organisms, from soil collected from a site at which puffballs multiply, that would decompose the material. Although a large number of samples were examined by the soil-plate method, no effective organisms were found. Recently, decomposition was found to have been begun in a water suspension of the material that had been exposed to the air. Serial transfers with puffball mycelium as sole energy source of the organisms present have been successful, and it is hoped that the organism or organisms responsible will be isolated. An examination of their effect on the material may then throw light on its nature. Chemical studies have also been undertaken in the hope of being able to differentiate chemically between chitin and an insoluble material with a high glucosamine content that is present in amounts of up to 18 per cent (calculated as a glucosamine polymer) in the puffball. The material is not acetylated, probably occurs in a number of other fungi and may be of importance in the protection of chitin from enzymic attack. It is hoped to investigate its relation to " lycoperdin ".

The editing of Volume II of *Modern Methods of Plant Analysis* has been completed, and the remaining volumes are almost entirely in first proof form. A contribution on plant ureides has been prepared for Volume IV. It is believed, as a result of the literature survey entailed, that these compounds may prove of considerable importance in the protein metabolism of legumes and some other groups of plants, and may perhaps be of interest in nucleic acid metabolism.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

New laboratories for the mycologists were built but not finished in time to be occupied during the year. The glasshouses and insectary occupied late in 1953 proved a valuable addition for virus work, though the summer of 1954 did not subject the ventilating system to a severe test.

P. H. Gregory left at the end of January to become Professor of Botany at the Imperial College, London University, and Brenda M. Hamlyn in June to be married. New appointments during the year were E. W. Buxton, T. Mulligan and D. M. Firth (Dunholme Field Station). G. E. Russell of the Plant Breeding Institute, Cambridge, worked in the department for six months.

As the guest of the Indian Science Congress Association, F. C. Bawden attended the Science Congress at Hyderabad in January and spent three weeks afterwards visiting agricultural research stations and universities in various parts of India. B. Kassanis worked for two months at the Station Centrale de Pathologie Végétale, Versailles, learning the techniques of plant-tissue culture. F. C. Bawden, L. F. Gates, Mary D. Glynne, J. M. Hirst, B. Kassanis and F. T. Last attended the International Botanical Congress at Paris, and A. Kleczkowski the International Congress of Photobiology at Amsterdam. R. Hull attended the winter and summer meetings of the International Institute of Sugar Beet Research held respectively in Brussels and Eire and, with J. Blencowe, the Virus Yellows Colloquium at Bergen-op-Zoom.

Viruses and Virus Diseases

Strains of tobacco mosaic virus

We have previously reported that extracts from plants infected with tobacco mosaic virus (TMV) contain a range of specific particles that differ greatly in length and in their ability to cause infection, the shortest being almost or wholly uninfective, though they all seem to contain the same antigens. The proportion of short particles is now much less than we used to find; we cannot account for this except by postulating that our stock culture of TMV has changed. Some indirect support for this idea was obtained by studying several strains of TMV and finding quantitative differences, but with none has the ratio of short to long particles been as great as it was some years ago. The small yield of uninfective particles has prevented critical work on their chemical constitution, and we have not been able to conclude whether they contain nucleic acid or not.

The particles of all the strains are indistinguishable by electron microscopy, but the strains differ from one another in many ways. One from the United States seems not to infect tomato, is precipitated with much less salt than other strains and, a confirmation of American work, is more readily inactivated by ultra-violet light.

This one, and another from India, although serologically related to our stock culture of TMV, seems to share no antigens with cucumber viruses 3 or 4, which are serologically related to the stock culture. Should further work confirm this, it will be the first example known of viruses showing this type of relationship; that is virus A sharing antigens with B and B with C, but not A with C. (Bawden.)

Inactivation by ultra-violet radiation

One character shared by the four strains of TMV we have studied is that preparations partially inactivated by exposure to ultra-violet radiation have the same infectivity, relative to unirradiated preparations, whether inoculated plants are kept in the light or dark after inoculation. With six other viruses, tomato bushy stunt, Rothamsted tobacco necrosis, cucumber mosaic, tobacco ringspot, cabbage black ringspot and potato virus X, irradiated preparations produce more lesions when inoculated plants are placed in the light than when they are placed in the dark. The quantitative response to visible light differs considerably with the individual viruses and is greatest with potato virus X, irradiated preparations of which may give twenty or more times as many lesions on plants in the light as in the dark. The response with this virus is large enough to study the conditions that give the response. Bright light is not necessary, a good response being given at 40 foot candles. The length of time needed in light depends on the time between inoculation and the first exposure to light. Most of the response happens within 2 hours of inoculation, but the numbers of lesions increase with exposure to light up to 6 hours after inoculation. Fifteen to 30 minutes immediately after inoculation has little effect, but if plants are placed in the dark for the first hour after inoculation, then 15 and 30 minutes exposure to light greatly increases the number of lesions. After 2 or 3 hours in the dark, exposure to light has little effect. It seems that, during the first hour or so after inoculation to leaves, the virus particles undergo some change and enter a state in which the ability of those damaged by ultra-violet light to multiply is affected by visible light. This sensitive state is transitory, lasting for about an hour, and if during this time virus particles do not start to multiply, they seem to be destroyed. (Bawden and Kleczkowski.)

A change in the condition of Rothamsted tobacco necrosis virus (RTNV) during the first hour or two in inoculated French-bean leaves is also suggested by experiments in which inoculated leaves were irradiated with ultra-violet light. At times up to 1 hour after inoculation, a constant amount of irradiation gives a constant decrease in the numbers of lesions produced by a given inoculum, but after that it has less effect. At 25° C. the results are compatible with the hypothesis that substances that absorb ultra-violet start to be synthesized about 1 hour after cells become infected, that new virus particles start to appear between 2 and 4 hours, and that some of these move from the epidermis to the palisade cells by 6 hours after infection. Similarly, experiments with inhibitors of infection, like ribonuclease, suggest changes in infected cells after about 1 hour. Up to 1 hour, applying ribonuclease to inoculated leaves decreases the numbers of lesions produced, but not afterwards. However, the interpretation is uncertain, for it may be that during

this hour inoculated cells recover from injuries made when they were inoculated with the virus and become impermeable to such large particles as ribonuclease. Inhibitors with small particles, e.g., trichothecin with French bean and thiouracil with tobacco, have effects if applied many hours after inoculating the viruses, but these can penetrate deeply into uninjured leaves and may act by preventing the spread of virus from cell to cell rather than by affecting virus multiplication in cells where it has already been initiated. (Bawden and Harrison.)

Effect of temperature on virus multiplication

Virus multiplication was estimated by assaying the infectivity of sap expressed from leaves at intervals after inoculation. From 1 to 3 days after inoculation, the optimum temperature for multiplication of RTNV in French-bean leaves was 22° C. Three days after inoculation, the virus content of leaves kept at 22° C. was 4,000 times greater than in leaves at 10° and 1,000 times greater than at 30° C. The factor by which virus concentration increased between 1 and 3 days after inoculation, decreased as the temperature increased from 10° to 30° C. When leaves kept at 22° C. for 2 days after inoculation were put at 30° C. for a day, their virus content dropped to one-fifth; it increased again when they were returned to 22° C. It is thought that RTNV is simultaneously synthesized and broken down at all these temperatures, but that the ratio of breakdown to synthesis increases as the temperature increases.

For 5 days after inoculation, tomato aucuba mosaic virus increased in inoculated *Nicotiana glutinosa* leaves more rapidly at 27° and 30° C. than at 33° and 36° C. At 27° and 30° C. most lesions were necrotic, whereas at 33° C. nearly all were chlorotic. Only a few chlorotic lesions developed at 36° C.

The period after inoculation during which irradiating leaves with ultra-violet decreased the number of lesions produced by RTNV was shortened by increasing temperature up to 22° C., but not between 22° and 31° C. This period is thought to be that needed for virus to multiply in and move out of epidermal cells into deeper tissues. (Harrison.)

Inhibitors of infection

The way in which substances like ribonuclease and chymotrypsin inhibit infections by plant viruses is still uncertain. Both these enzymes also inhibit the infection of *Rhizobium* sp. by bacteriophage, and in this system it seems that the two act in different ways. Ribonuclease acts by preventing the phage from combining firmly with the bacteria. Chymotrypsin does not affect this combination, but apparently inactivates the phage when it combines with the bacterium, although it does not inactivate free phage. It was thought that experiments resembling those with bacteriophage might throw light on the way in which inhibitors affect plant viruses, but before they could be made it was necessary to have some method of measuring the amount of virus that combined with host cells or fragments of them. For this purpose tobacco leaves were ground and then suspended in solutions of TMV. After incubating the mixtures, the solids were removed and the virus in the supernatant

fluid was assayed. Although the ratio of the weight (dry) of the ground leaves to virus was over 10^7, the infectivity of the supernatant fluid did not differ from that of the control in water. Hence, it seems that freshly ground leaves contain no large particles with which the virus combines specifically, as do bacteriophages with their host bacteria. (Kleczkowski.)

The statistical analysis of local-lesion counts

As numbers of local lesions produced by plant viruses are not normally distributed and their standard errors vary with their magnitude, they are not amenable to customary methods of statistical analysis. A transformation $z = \log_{10}(x + c)$, in which x is the number of lesions per leaf or half leaf and c a constant, has already been proposed that is appropriate when mean values of x exceed 10. In many kinds of work, however, fewer lesions than this are unavoidable, and for these a new transformation has been derived. It is $z = \log_{10} \frac{1}{2}(x + c + \sqrt{x^2 + 2cx})$, and can be used when mean numbers of lesions exceed about 1·5. The results of the two transformations converge as x increases. A table of values of z has been calculated that makes the new transformation as easy to use as the old. (Kleczkowski.)

Tissue cultures

A series of tissue cultures, using virus-infected roots and callus tissue, was produced as a preliminary to starting work on the factors that affect virus multiplication. In France virus-free potato plants have been produced by culturing the excised stem meristems from infected plants. This suggests that the ability of viruses to give systemic infections does not extend to invading these meristems, and work was started to find how virus concentration varies through plants. Tomato roots infected with TMV were grown in White's medium, then cut into pieces, macerated and the extracts assayed for their virus content. Although all contained virus, the older parts contained very much more than the younger ones. Similarly, the enclosed buds of systemically infected tobacco plants contained much less virus than the young leaves, and these less than the well-developed ones. In these tests the youngest tissues used were not exclusively meristematic, but further tests with more refined techniques will be needed before deciding whether or not the apical meristems contain virus. (Kassanis.)

Carnation latent virus

The virus described last year as latent in many stocks of carnation has now been found to be serologically related to one that often occurs in normal-looking plants of many potato varieties. All plants of some varieties, for example King Edward and Arran Victory, that have so far been tested contain it. Although serologically related, the viruses from carnation and potato are far from being antigenically identical. Also, they are transmitted in different ways and they infect different plants. The strain from carnation is transmitted by *Myzus persicae* and infects sweet william, *Chenopodium amaranthicolor* and sugar beet, but not potato or tomato. The strain from King Edward potatoes has not been transmitted by *M. persicae*; it infects tomato, but not the other species listed.

The strains in different potato varieties also seem to differ, for one in Arran Victory has not been transmitted to tomato. The potato strains are almost certainly the same as the viruses described in Holland as potato virus S. (Kassanis.)

Electron microscopy

The electron microscope has been much used for routine examinations of virus preparations, but it has been mainly occupied by the study of thin sections of infected plants and by developing methods for counting virus particles. Our machine is not well adapted for such kinds of work, because it does not permit large areas to be first surveyed at a low magnification as a preliminary to selecting areas for detailed examination at high magnification. One modification that has helped to speed up the work is the addition of a " Stigmator ", a device that allows the residual astigmatism of the objective lens to be compensated while the machine is operating instead of needing to open the microscope and remove the pole piece. In studying the changes in tobacco leaf cells caused by infection with TMV, the most suitable material seems to be the youngest leaves as they become invaded by virus coming from older inoculated leaves. This method provides a successive series of leaves of approximately the same size and avoids many of the difficulties experienced in preparing sections from fully-expanded leaves. No morphological changes have been detected during the early stages of infection, even though the virus is multiplying rapidly. It is impossible to be sure whether no changes occur or whether, at this stage, only a few of the cells are infected and these have not been encountered. At about the time inclusion bodies begin to form, some of the chloroplasts change in appearance, and the usual layer structure of the grana is replaced by granular vacuolate material. The thinnest sections show that the granules have a similar cross-section to TMV particles; the cut surfaces of such chloroplasts, when sectioned, resemble the cut surfaces of virus particles in the inclusion bodies. This suggests that the plastids may be one site where the virus multiplies, but is far from conclusive.

To develop the spray-drop technique of Backus and Williams into a routine method for counting virus particles, many technical difficulties have had to be overcome. When dealing with impure or partially purified virus preparations, the highest resolution is needed; this requires smaller drops than those used by Backus and Williams, which in turn calls for smaller standard particles than the Dow polystyrene latex spheres. The Plastics Division of Imperial Chemical Industries has kindly prepared for us a polyvinyl chloride latex, with particles about 0·1 μ diameter. The particles vary more than the Dow latex, but are sufficiently uniform for errors to be removed when enough are counted to give good statistical accuracy in determining the volume of droplets. The spheres aggregate at below pH 5·5, and virus preparations must be above pH 6·0 when mixed with the latex. Using the polyvinyl latex, droplet traces can be made small enough to be photographed at the highest magnification, thus making the best use of the microscope's resolving power. The method works well with purified virus preparations, but is unlikely to do so with impure preparations of viruses that have spherical particles, for it is difficult to identify these particles when

surrounded by other material. Another difficulty is that the 60-kV electrons in our microscope do not give a picture bright enough to count all the particles on the screen; to ensure accuracy, therefore, all droplet traces have to be photographed.

The rapid freeze-drying method described by Williams for preventing specimens from flattening during drying has been tested, but has given many difficulties. Our atmospheric humidities are so high that the air carrying the droplets into the freezing zone must be dried, or the mounts become covered with "snow", which prevents the drops from impacting on them. Also, our supplies of volatile salts are impure, and residues from these obscure the pictures. Some success was achieved by a less elaborate form of freeze drying. The specimen is mounted, as a large drop or as a spray droplet, on a grid held in a deep recess of a block cooled to −70° C. by a mixture of dry-ice and alcohol, when the block is placed in a vacuum and the ice sublimed. (Nixon and Fisher.)

Potato virus diseases

Field experiments at Sutton Bonington were made to find how varying the times of planting and lifting potatoes (King Edward) affects their yield of tubers, the proportion of "seed" infected with leaf roll and virus Y, and the cropping power of virus-free "seed". Results from a trial started in 1953 are shown in the table, the figures in brackets being the yields in tons of tubers per acre and the others being the percentage of healthy "seed". When grown to maturity, the biggest yields came from the earliest planting, but when grown for 12 weeks only they came from plantings in May and June; plantings in these two months and April, however, gave the smallest proportion of healthy "seed". The viruses became most prevalent in the crop planted in June, because the plants were young and susceptible during June and July when aphids were most active. Virus-free "seed" from the crop planted in August yielded significantly less than that from earlier plantings.

The yields and health of tubers from potato crops planted and lifted at different times

	Time of Planting				
	April	*May*	*June*	*July*	*August*
Lifted					
12 *weeks after planting*	*100(4)	95(9)	23(7)	46(4)	93(4)
After death of haulm	35(26)	37(21)	7(10)	43(7)	93(4)

* Figures in brackets are yields of tubers in tons per acre: others are percentages of healthy "seed" tubers.

In co-operation with the Insecticides Department experiments on the use of persistent insecticides to control the spread of potato virus diseases were continued in several localities. The results of the 1953 experiments again indicated that insecticides effectively prevented the spread of leaf roll from infected to healthy plants in the same crop, and they usually decreased the spread of virus "Y". They did not prevent viruses from being introduced into the crops from outside sources, but, unless there are severely affected stocks near, few plants usually become infected in this way compared with those infected by spread within a crop. (Broadbent.)

Viruses of cruciferous crops

The transmission of cauliflower mosaic virus (CLMV) by aphids differs from other non-persistent viruses, and the manner in which it behaves differs with different aphids. Previously fasted *Myzus persicae* give as many or more infections after infection feeding times of 2 minutes as after 24 hours, whereas *Brevicoryne brassicae* give more after 24 hours, and a previous fast does not increase the number. To see whether these differences could be correlated with differences in feeding behaviour, the feeding habits of these aphids and *Myzus circumflexus* were compared. The average times for which fasted *M. persicae*, *M. circumflexus* and *B. brassicae* remained with their stylets in leaves at the first penetrations were 37, 30 and 210 seconds; for unfasted individuals the times were 65, 36 and 360. When fed on plants infected with cabbage black ringspot virus (CBRSV), the penetration times that made individuals infective were nearly all between 15 and 120 seconds, and mainly between 60 and 120. Although the proportion of unfasted aphids that penetrated for these periods was almost as high as of fasted ones (the average penetration time was higher because the scatter was greater and some unfasted aphids penetrated for long periods), only few of the unfasted aphids became infective, seven *M. persicae* compared with eighty-five fasted ones. *M. circumflexus* behaved very similarly to *M. persicae*, but transmitted only a quarter as often. *B. brassicae* gave only one-tenth as many transmissions as *M. persicae*. We have previously given evidence that CBRSV is more concentrated in the epidermal than in other cells of infected leaves, and these results suggest that fasted *M. persicae* imbibe fluid from the epidermis more readily than do the other aphids. If aphids carry CBRSV in drops of sap contaminating their stylets, then these drops seem to be carried inside the stylets, for exposing the beaks of infective *M. persicae* to ultra-violet light did not affect their ability to transmit. Irradiating leaves infected with CLMV had less effect on the numbers of *B. brassicae* that became infective after 2-minute infection-feeding times than with *M. persicae*, though both aphids behaved similarly with CBRSV. With 24-hour infection-feeding times, both species behaved alike with both viruses, as many transmitting from irradiated as from unirradiated leaves. Aphids feeding on healthy plants remained infective with CLMV for longer than with CBRSV. (Watson, Hamlyn and Mulligan.)

The main conclusions from a field trial made to study how mosaic and manuring affect two varieties of cauliflower (St. George and Early Extra Roscoff) were: (*a*) the incidence of CLMV and of "tip-burn" ("scorch") increased with increasing amounts of nitrogen, but "tip-burn" was not caused by CLMV; (*b*) the number of plants that died during winter was increased by nitrogen, but in St. George was unaffected by CLMV; (*c*) CLMV decreased curd size and increased the number of "bracty" and loose curds; (*d*) increasing nitrogen also increased the "bracty" curds and accentuated the loss of yield by CLMV; (*e*) moderate dressings of nitrogen increased the yields from uninfected plants, but high levels decreased them; (*f*) the number of marketable curds was much decreased by CLMV and less by high nitrogen; (*g*) CLMV and high levels of nitrogen made plants mature a few days earlier; (*h*) the adverse

effects of mineral nitrogen were more pronounced with hoof than with farm-yard manure; (*i*) filling up gaps a month after planting the crop was not worth while, as fewer than half those planted late produced marketable curds.

The effect on the incidence of cauliflower mosaic of surrounding cauliflower seedbeds with single rows of barley was again tested. At Efford there were too few aphids and infections for results to be significant. At Luddington early-sown barriers decreased the incidence to one-quarter of that in control plots in four-row and to one-half in twenty-two-row seedbeds. When barley was drilled at the same time as the cauliflower seed, the decrease was slightly less.

Aphid infestations and the movement of winged aphids was studied by operating twenty-two sticky traps in different parts of England. Of 278 winged *M. persicae* bred on plants infected with CLMV and tested for their ability to infect healthy plants, 51 did so: of 45 winged aphids from plants with CBRSV, 12 caused infections. (Broadbent and Heathcote.)

A strain of turnip yellow mosaic virus found damaging cruciferous crops near Newcastle differs from the strain prevalent near Edinburgh. The two are both transmitted by flea-beetles and are serologically related, but they are far from antigenically identical and do not crystallize in the same ways. The Newcastle strain also differs from the Edinburgh one in readily infecting and severely affecting cabbage, cauliflower and kale. Another flea-beetle-transmitted virus was found at Edzell (Scotland) affecting turnips in 1953. It is not serologically related to turnip yellow mosaic virus and has provisionally been called turnip crinkle virus. It has a thermal inactivation point around 80° C. and infects cabbage and cauliflower, but does not damage them severely. (Broadbent and Blencowe.)

Sugar-beet virus diseases

The susceptibility of various varieties of wild and cultivated beet to yellows virus (SBYV) was tested. All proved equally easy to infect with aphids, but they showed symptoms of different severity when infected. *Beta maritima* varieties were more tolerant than crosses between *B. maritima* and *B. vulgaris*, and these more than *B. vulgaris*, some varieties of which, and particularly a Klein "D" non-bolter, were very severely affected. The severity of symptoms shown by varieties under glass was correlated with loss of yield in the field. The severity of symptoms was also correlated with the antigen content of plants, estimated by titrating the sap against SBYV antiserum. In all varieties the antigen content was highest about 3 weeks after infection, when the content started to fall, falling more rapidly with tolerant than with intolerant varieties.

The seedlings of one variety often show more severe symptoms if colonized by several infective aphids than if colonized by single aphids. This may explain a German claim, contrary to our experience, that *Aphis fabae* transmits only avirulent strains of SBYV. When seedlings were colonized with 3 aphids, conditions in which *M. persicae* infected 50 out of 50 plants, *M. circumflexus* infected 46, *Macrosiphum pisi* 31, *A. fabae* 13 and *B. brassicae* 0. The average severity of symptoms shown by the 13 plants infected by *A. fabae*

was less than those shown by plants infected by *M. persicae*, but plants colonized with 20 *A. fabae*, when all the plants became infected, developed the same severe symptoms as those infected by *M. persicae*. The apparent virulence of a culture of SBYV can often be increased by serial passages using many aphids per plant and decreased by serial passages with single aphids. Some of these differences may reflect an effect of the amount of virus initially introduced into seedlings, but infected plants may also contain several virus strains which are sometimes transmitted separately by single aphids. (Watson and Russell.)

The relationship of yellow net virus (YNV) to SBYV remains uncertain, but its multiplication is decreased by the presence of strains of SBYV, and more so by virulent than by avirulent strains. On its own, it cripples beet plants and turns them almost wholly yellow, and the characteristic yellow lines following the veins may be typical of dual infections with SBYV. YNV does not readily invade plants already infected with avirulent strains of SBYV and produces only a few scattered spots on plants with virulent strains. Plants already infected with YNV, however, are not protected against infection with virulent SBYV, which seems to multiply normally and produces its typical symptoms on young leaves; the yellow net symptoms persist on the old leaves, but do not develop on leaves produced after the plant becomes infected with virulent SBYV. By contrast, avirulent strains of SBYV protect plants from normal invasion by virulent strains; not only do the symptoms remain mild when plants are inoculated with virulent strains, but the antigen content of the plants also remains well below that typical of plants infected with the virulent strain alone. Both SBYV and YNV infect *Nicotiana clevelandii* and *N. biglovii*, but yellow net is difficult to recover from them by aphids; SBYV but not YNV infects *Chenopodium amaranthicolor*. (Hull and Watson.)

Uniform crops of three commercial beet varieties were inoculated in June with a strain of SBYV that causes etch symptoms, a strain that causes only chlorosis or a mixture of the two. The aphids used to inoculate the plants were killed by spraying, and the plots were later sprayed at regular intervals. The varieties suffered equally from infection and the yields, compared with 19·02 tons acre for the healthy plots, were 10·85 with the etch strain, 9·08 with the other and 8·80 with the mixture. There was less difference in the appearance of the plots in the field than was expected from the behaviour of the strains under glass. Each plant was "scored" for the severity of symptoms in August, using a scale from 0 for a healthy plant to 5 for one severely stunted and with all its leaves showing some yellowing or necrosis. Most infected plants were in category 3, but the range on plots inoculated with the etch strain was wider than on the others. With the yellowing strain, the range was 1–4, with more in category 2 than 4; the range with the etch strain was 0–5, with most in 3 and 4, and with the mixture was similar, except that all plants were infected and fewer came in categories 1 and 2. There was no necessary correlation between severity of leaf symptoms and yield, but plants with slight symptoms usually gave large roots, and those with severe symptoms small ones. Infected plants of one variety gave many more large roots than the others, and although in total it was not more tolerant

than the others, this suggests that it contains tolerant genotypes that might be useful in a breeding programme.

Differences in tolerance were also found in experiments comparing the effects of SBYV on seven inbred lines of sugar beet, but the most tolerant variety yielded less than the others when uninfected. Measuring tolerance by effects on yield, however, is complicated by the fact that some varieties suffer relatively more loss than others if infected early in life but less if infected late. Progenies from self-pollinated plants selected in earlier years for tolerance were again tested, and showed great differences in severity of symptoms. The size of roots did not always reflect severity of leaf symptoms, but some of these progenies gave a larger yield of roots than comparably infected commercial varieties. Three polyploid lines derived from Klein E by the Plant Breeding Institute, Cambridge, yielded as much sugar per acre as commercial varieties when uninfected, but suffered twice the loss of sugar when infected with SBYV. (Hull and Firth.)

Experiments to test how spraying with systemic insecticide affects the incidence of yellows in root crops were made on six crops in Lincolnshire and Norfolk. The proportion of plants with yellows at the end of the season was more than halved by one spray with "Systox" at 400 g./acre, applied either in mid-June or early July; spraying on both occasions had little additional effect. A third spray at the end of July decreased the proportion of infected plants by one-third. Although less than 40 per cent of the plants on the unsprayed plots became infected, and many of them only after mid-August, spraying increased yield by from 1·75 to 3·5 cwt./acre of sugar.

An experiment at Dunholme tested the effect of sprays on early- and late-sown plots, with wide and narrow spacing, and with different amounts of fertilizer. Fertilizer and spacing did not affect the incidence of yellows, but early sowing increased it, and spraying decreased it to one-fifth. A similar experiment at Sprowston has not yet been analysed.

In co-operation with the Sugar Corporation's agricultural staff, replicated 1-acre plots were sprayed by contractors with the systemic insecticide "Metasystox". At seven of the eighteen sites yellows did not spread enough for spraying to have effects. In two fields near Colchester, where half of the plants on unsprayed plots contracted yellows, one spray decreased the incidence to one-quarter and increased yield by $\frac{1}{2}$–$\frac{3}{4}$ tons/acre of roots. All the plants in two other crops in the same district became infected whether sprayed or not. However, the sprayed plots took longer to become 100 per cent infected, and yielded an extra 3 tons/acre of roots. A second spraying gave no additional benefit. Spraying also decreased the incidence of yellows in crops near Bury St. Edmunds and Peterborough, but effects on yield were not measured. *Aphis fabae* infested the sugar beet in Suffolk and Norfolk. These were killed by "Systox" and "Metasystox", and it is not possible to say what proportion of the increased yield should be attributed to the control of these pests. (Blencowe, Gates, Hull and Firth.)

Seed crops planted with unsprayed stecklings had 73 per cent infected plants whereas the percentage of infected plants in crops planted from stecklings sprayed three times in the autumn was :

" Systox ", 30; " Hanane ", 28; " Schradan ", 34; and " NC7 ", 22.

To compare the rate at which different insecticides kill aphids, plants were sprayed and then later colonized with winged *M. persicae* and covered with tumblers. When colonized 24 hours after spraying, " Malathon ", " NC7 ", " Metasystox " and " Hanane " killed aphids within 5 hours, and " Parathion " and " Systox " between 5 and 17 hours. When colonized 4 days after spraying, the first four still killed aphids in periods of 5–17 hours. The kill is too slow to prevent infective aphids from infecting healthy seedlings, though the proportion that become infected was slightly decreased by " Malathon ", " NC7 " and " Parathion ".

Beet seed was soaked in various insecticides to see whether this would protect emerging seedlings against aphid infestations. When seed soaked in 2 per cent " Hanane " was sown thickly the seedlings had fewer aphids a month after emerging than did control seedlings, but at the seed rate normal for root crops the treatment had no effect. " Systox ", " Metasystox ", " Malathon " and " NC7 " gave less protection against aphids, killed some seedlings and stunted others. " Pestox III " did not protect against aphids. (Gates.)

Further tests with " Systox ", " Parathion " and " Pestox 14 " sprayed on mangolds and fodder beets a few days before harvest showed that, to kill aphids and prevent infestation in clamps, all three need to be applied at three times the concentration normally used on sugar beet in the summer.

Maleic hydrazide, a growth-regulating substance, was again tested for its ability to check sprouting of stored mangolds and fodder beets with the idea that this might decrease aphid infestations. Sprouting was almost completely halted on clamped Orange Globe mangolds sprayed on 16 October with 0·25, 0·5 and 1·0 per cent maleic hydrazide, and on Hunsball fodder beet sprayed on 2 September with 1 per cent maleic hydrazide, and 4 November with 0·25 and 0·5 per cent maleic hydrazide.

When stored at about 40° F. in a cellar, unsprayed mangolds sprouted rapidly, and by 5 January had many sprouts 7 inches long. Those sprayed with maleic hydrazide on 16 October produced shoots 2 inches long by 5 January, but the shoots soon died; more appeared, and some were 3 inches long on 15 February, but these also died. On 29 March three-quarters of the sprayed roots had no shoots, and those on the others were probably too small to support a population of *Myzus persicae* over the winter. (Cornford.)

Samples from commercial sugar-beet stecklings planted at Dunholme varied more in the percentage of plants with yellows than in the previous three years. More beds were rejected this year for commercial planting because they contained more than 1 per cent infected plants in the autumn of 1953. Rejecting five beds decreased the mean percentage of infected plants in beds from the north of England from 10·5 to 7·8; rejecting twenty-six beds from eastern England, where control of yellows depends upon spraying with insecticides, decreased the mean percentage of infected plants from 25·2 to 4·1. The average percentage of infected plants in crops from all steckling beds was 17·4, but in those certified for planting it was 5·4. The mean percentage of plants with yellows in seed crops planted from beds raised under cover crops was 2·5. The

consistently good control of yellows obtained by growing stecklings under barley is increasing the use of this measure.

In the autumn of 1954 the mean percentage of infected plants in eighty-three sugar-beet steckling beds was only 0·17, equal to the previous lowest, in 1951. All steckling beds were certified as being usable. Mangold and fodder-beet steckling beds, especially those in south Lincolnshire, were less healthy, containing up to 8·5 per cent infected plants, and the average for 137 beds was 2·9 per cent. (Hull and Firth.)

Of 200 plants from thirteen different weed species collected in February from sites where they had opportunity to contract yellows in 1953, six contained viruses transmissible by *M. persicae* to sugar beet. Two plants of *Senecio vulgaris* and one of *Capsella bursa-pastoris* contained SBYV. One *C. bursa-pastoris* and one *Stellaria media* contained what are tentatively diagnosed as strains of cucumber mosaic virus. One *Rumex crispus* contained an unidentified virus that stunted sugar beet and produced a mottle and yellowing of the leaves. (Hull.)

Mycology

Potato diseases

To study the origin and course of outbreaks of potato blight, tubers infected with *Phytophthora infestans* were planted among healthy ones. Only two out of 246 such tubers produced plants with stem lesions, and in only one could the fungus in the lesion be certainly traced to the tuber. This one produced a lesion on 28 May, the earliest date that blight has been noted in the field at Rothamsted. Blight did not appear generally in the crops until the end of July, by which time there had been six periods at crop level corresponding to those specified as the "Beaumont warning" for blight. On each of these occasions blight spread to plants near the one with the initial lesion. Thus, the use of a "zero" date, before which "Beaumont warnings" are ignored in forecasting outbreaks, is explained by the need for about six "generations" of infections from over-wintering sources before the fungus is plentiful enough to affect crops generally.

Although blight became general at about the same time and developed at the same rate as in 1953, in 1954 two sprays with a copper fungicide increased yield by 2·4 tons/acre, compared with only 0·5 tons in 1953. The difference can be explained by the cooler summer of 1954, which meant that the crop was later in maturing. When blight appeared in 1953 about two-thirds the final yield of tubers on sprayed plots had already been formed, whereas only one-third was formed at the same time in 1954.

Spore traps operated in potato fields showed the greatest concentration of spores of *P. infestans* yet measured, 14,700 sporangia per cubic metre on 21 August. (Hirst and Stedman.)

A fungus indistinguishable from *Oospora pustulans*, the cause of skin spot of tubers, was found frequently in brown lesions on the roots, stolons and stems below ground. Isolates from typical skin-spot lesions on tubers and from brown lesions both increased the number and size of such lesions when added to soil at the time the potatoes were planted. Tests to see whether the fungus from stems will cause skin spot are not yet complete. (Hirst and Salt.)

Spore trapping

Automatic spore traps were again used to study the dispersal of spores of *Venturia inaequalis*, the cause of apple scab. Conidia are usually assumed to be dispersed only in wet weather, but most were caught on dry afternoons, and there is evidence that rain washes them out of the air.

Changes in the spore content of the air in the open are difficult to interpret because of interacting biological and physical factors. Trapping in the open is therefore being accompanied by tests in the partially controlled conditions of the wind tunnel. After a thorough wetting, scabby dead apple leaves ejected ascospores freely, the number liberated reaching a peak between 1½ and 3 hours after wetting. After atomizing water equivalent to 0·2 mm. of rain evenly over the leaves, few spores were caught, suggesting that dew is unlikely to liberate many. Ascospores of *Ophiobolus graminis*, the cause of take-all of wheat, were liberated in the same conditions as *V. inaequalis*, but more quickly, the peak catches coming in less than an hour after thoroughly wetting infected straws. (Hirst and Stedman.)

Spores of *Sporobolomyces roseus* are often the predominant type caught in spore traps operated in the open. This species seems a normal contaminant of leaf surfaces, reaching large numbers on ageing leaves, particularly at high humidities. It seems not to influence the development of leaf pathogens or to be influenced by them, but *Tilletiopsis minor*, another innocuous fungus that occurs on leaves during July and August, does suppress it. (Last.)

Cereal diseases

Further evidence was gained that the optimum seed rate for wheat depends on whether or not the land is infested with eyespot (*Cercosporella herpotrichoides*) and take-all. If it is, then a seed rate of 1½ bushels of Squarehead's Master yields a better crop than a seed rate of 3 bushels, but on clean land the higher seed rate gives as good as or better yield. Seed rates in bushels that are appropriate for one variety are not necessarily appropriate for others, because grain sizes differ. Holdfast drilled at 1½ bushels, for instance, produced as many plants per foot of row as the larger-grained Cappelle drilled at 3 bushels. The proportion of small grains and weed seeds in harvested grain varied widely in different experiments. In one at Rothamsted, Cappelle sown at 3 bushels on land contaminated with take-all and eyespot gave a threshed yield of 35·3 cwt./acre, but this included 5·7 cwt. of thirds, weed seeds and other impurities and 6·0 cwt. acre seconds, leaving only 23·6 cwt. acre dressed corn. This contrasts with Cappelle in another experiment on land almost free from take-all and eyespot, in which a yield of 49·4 cwt./acre included only 1·2 cwt. acre of small grain, no weed seeds and 2·1 cwt. acre seconds, giving 46 cwt. acre dressed corn.

The effect of seed rate on lodging in spring-sown Proctor barley was tested at three levels of nitrogen. By 22 July plots sown with 1, 2 and 3 bushels had respectively 3, 17 and 36 per cent of their areas lodged in plots receiving 1½ cwt. sulphate of ammonia, 27, 63 and 85 per cent in those receiving 3 cwt., and 33, 88 and 91 per cent lodged in those receiving 4½ cwt. sulphate of ammonia. This

striking increase in lodging with increased seed rate and nitrogen was evident throughout July, but during the wet August most of the crop fell down and was flat by harvest on 2 September. The total grain harvested averaged 42·9 cwt./acre; a seed rate of 2 bushels yielded 2·5 cwt./acre more than 1 bushel, and 3 bushels gave an insignificant further increase. One dose of nitrogen had no significant effect, but a second decreased yield by 1·5 cwt./acre. The amount of " tail corn " increased with increasing seed rate and nitrogen, and when both this and weed seeds were removed, the yield of dressed grain from plots sown at 1, 2 and 3 bushels/acre was similar; it was decreased by 3 and 3·4 cwt./acre by the first and second doses of nitrogen respectively.

Disease surveys of the classical and other wheat experiments showed an exceptionally high incidence of eyespot. (Glynne, Salt and Slope.)

Continuing experiments to test the effect of date of sowing on the incidence of powdery mildew, wheat was sown on four dates from 6 March to 21 April and barley on 22 March and 5 April 1954. Mildew was not observed until late May, and the last sown crops became the most heavily infected. The barley formed part of an experiment to measure how mildew affects yield. A susceptible (Plumage Archer) and resistant (Haisa II) variety were sown on both dates, and half of each sowing was sprayed with lime sulphur five times from 13 May to 8 July. Plants infected with *Erysiphe graminis* were placed in the plots in mid-May. Unsprayed Plumage Archer had ten times as much leaf infected as the sprayed, and leaves died from mid-June onwards. By 23 June, mildew had decreased the area of leaf on the main stems of the unsprayed plants by 16 per cent in the early-sown crop and by 36 per cent in the late-sown. The unsprayed plots yielded significantly less than the sprayed, 13 per cent less for the early and 22 per cent for the late sowing.

Unsprayed Haisa II developed only few pustules, and spraying did not affect yields. (Last.)

Pea diseases

From diseased peas a range of Fusaria was isolated that severally and together produced a variety of syndromes. *Fusarium oxysporum* f. *pisi* and *F. oxysporum* var. *redolens* cause wilt, *F. solani* causes foot rot, and *F. oxysporum* and *F. solani* together cause a condition resembling " St. John's disease ", previously recognized only on the continent of Europe. " St. John's disease " is less severe than either foot rot or wilt. In affected plants *F. oxysporum* is dominant in the stele and *F. solani* in the cortex of roots and stems. Inoculating isolates of *F. oxysporum* f. *pisi* to a range of differential pea varieties identified a previously unrecognized race, which is provisionally called 3A.

The pathogenic strains of *F. oxysporum* cannot be distinguished by cultural or taxonomic methods. Three possible ways of identifying them, other than laborious tests for pathogenicity, are being studied. Antisera were prepared by injecting rabbits with spores and macerated mycelium, but detailed agglutination and cross-absorption tests will be needed before their value can be assessed. Pathogenic and non-pathogenic strains are being compared for their resistance to ultra-violet radiation, and the third method, which

shows promise, is to test their inhibition by growth products of soil actinomycetes. Of twenty actinomycetes so far tested, some consistently inhibited the growth of all eight selected strains and others inhibited none. *Streptomyces albidoflavus*, however, inhibited some strains but not others.

In attempts to gain some information on the genetics of pathogenicity and on the mechanism of recombination in *F. oxysporum*, several thousand conidia were irradiated with ultra-violet light to produce mutants. Cultural tests showed fifty-two mutants with deficiencies in their aminoacid metabolism and thirteen deficient in their nucleic acid metabolism. In addition, fifty-two mutants were obtained which were dwarf or otherwise morphologically different from the wild type. Their ability, and that of the heterokaryons between them, to infect peas is being tested.

Several cultures of *F. oxysporum* isolated from roots of diseased Sitka seedlings in forest nurseries proved pathogenic when inoculated to Sitka seedlings under glass at Rothamsted. They may contribute to the difficulties experienced in raising healthy plants in old nurseries. (Buxton.)

Club-root of crucifers

The technique of infecting seedlings in water-culture to obtain root-hair infections has been mentioned in previous reports, and some of the factors affecting numbers of infections have now been studied. In general, they resemble those affecting infections in soil. Young seedlings were grown singly in small tubes or vials containing spores of *Plasmodiophora brassicae* suspended in a dilute mineral nutrient solution (Hoagland's solution) and incubated at 25° C. in the dark. The logarithm of the mean number of infections per plant is linearly related to the logarithm of the spore concentration. Root-hair infections occurred equally readily at pH 5 and at pH 6, but there were many fewer towards pH 8. The concentration of the culture solution was important. Thus, diluting Hoagland's solution, at pH 5 or pH 6, to one-fifth of the standard concentration considerably increased infections, and it seems that the germination of spores is affected. The number of infections obtained, however, depends on the interaction of at least three factors: numbers of spores, concentration of the culture solution and its pH. With high spore concentrations, changes in pH or concentration have less effect. Similarly, at certain spore concentrations, diluting the solution diminishes the influence of pH. (Macfarlane.)

Sugar-beet diseases

Continued tests with fungicides to control seedling diseases of sugar beet gave further evidence of the benefits derived from soaking seed for 20 minutes in 0·004 per cent solutions of ethyl mercury phosphate; at thirteen out of fourteen sites this treatment produced an average of 25 per cent more seedlings than dressing seed with "Agrosan". In soil artificially contaminated with *Pythium debaryanum* and *Rhizoctonia solani*, pouring solutions or suspensions of various fungicides along the drills immediately before sowing much increased the number of seedlings that emerged; formalin increased the stand by more than 50 per cent. A drill with spray

nozzles mounted behind the coulters is being built to test the method further.

In the Docking district of Norfolk, and in other places with light, alkaline soils, sugar beet in June or July often become yellow, their leaf margins scorched and the laminae cupped. Tap roots are small, fanged, become horizontal at 3–4 inches below ground, and have a "beard" of laterals, many of which die. The "Docking disorder" is worse in dry weather and on land containing little organic matter. Severely affected plants are often infected with *Pythium* and *Rhizoctonia* sp., but when inoculated to sugar beet in glasshouses the isolated fungi fail to produce symptoms comparable with those in the field. Sugar-beet plants still grow poorly in affected soil that has been steamed. Both in pots and in the field, the condition can be alleviated by adding organic matter to the soil. The pathogenic fungi so far isolated from affected plants seem insufficiently virulent to cause the serious field condition; the effects on roots of young seedlings resemble those produced by extremely acid soils, and this, combined with the early leaf chlorosis and cupping, suggests a toxin may be the primary cause of the trouble with the fungi secondary. (Gates.)

Work was continued on the rotting of stored beet by *Botrytis cinerea*. This fungus does not rot beet cut during the summer, but after November they become susceptible. When untopped stored roots were cut lengthways and the cut tissue inoculated with *B. cinerea*, the lower parts of the roots became invaded but not the upper. With increasing age, more of the root becomes susceptible, and by about February only a small band of tissue immediately below the crown resists infection. Spore-germination tests with pieces of roots show that the resistant tissues contain a fungistatic substance, whereas the susceptible tissues do not, or at least not in detectable amounts. Bruised tissue provides an easier entry into roots than cuts. *B. cinerea* was also found to be the most important fungus causing rots of clamped mangolds and fodder beet. (Cornford.)

NEMATOLOGY DEPARTMENT

B. G. Peters

The following visitors have worked in the department during the year: Mr. N. D. N. Welford and Miss E. C. Mason from the National Agricultural Advisory Service, Cambridge (5 to 16 January); Mr. G. E. Thomas from the States Experimental Station, Jersey (25 January to 4 February); Mr. A. R. Al Adhami from Iraq (5 days in May); Mons. M. Luc from the Côte d'Ivoire (14 June to 17 July). Mr. Thomas required help in handling a large mass of experimental data: the others were interested in acquiring our laboratory and/or experimental techniques.

A new development for this department was marked by the arrival in April of Mr. H. E. Welch from the Insect Parasite Laboratory at Belleville, Ontario, who intends to work for two years on nematode parasites of insects.

For the Commonwealth Bureau of Agricultural Parasitology, J. B. Goodey and M. T. Franklin are working on a new edition of T. Goodey's *Nematode parasites of plants catalogued under their hosts* (1940), now seriously out of date.

Material and Methods

Root-knot material, received from Tanganyika, Nigeria, West Bengal, Canaries and Italy, has been tentatively identified and, where possible, confirmation has been sought from test inoculations of four key-plant species. Interpretation of the main diagnostic feature, the cuticular perineal pattern, has been facilitated by a set of photomicrographs of typical patterns kindly sent by Dr. A. L. Taylor of Beltsville, Md. (M. T. Franklin.)

In counting eggs from cysts of potato root eelworm the hypochlorite technique has been largely superseded by a squashing method: soaked cysts on a flat metal plate are crushed by a glass roller supported on side-strips $\frac{5}{1000}$ inch high and the cyst contents are freed from the cyst wall in a homogenizer. (E. Widdowson.)

The standard technique in which potato root eelworm cysts are floated from dried soil and then stored dry, is not satisfactory for cereal root eelworm cysts. Many newly-formed cysts fail to float, and cysts stored dry fail to hatch. The flotation technique has had to be modified, and cysts are stored wet at low temperature. (J. J. Hesling.)

For work on the race of *Ditylenchus dipsaci* attacking mushroom spawn, a thermostatically controlled chamber for the pot-culture of mushrooms has been constructed. (J. B. Goodey.)

Eelworm Population Changes

Heterodera schachtii

For the third time, all the Barnfield plots have been sampled to follow the population changes of beet eelworm. Larval counts are

not yet available, but the cyst counts show only a trivial increase in the mean for the whole field, compared with 1948 and 1946 :

Year	*Cysts per g. of soil (geometric mean)*
1946	0·388
1948	0·405
1954	0·427

Broadly speaking, manurial treatments and forms of nitrogen which favour high yields of tops and roots also favour high cyst densities. (J. J. Hesling and B. G. Peters.)

Heterodera major (J. J. Hesling)

Exploratory sampling across the fallow section of Broadbalk revealed some cereal root eelworm, mainly on the dunged plot; as a result, all treatments and sections have been sampled after ploughing. This eelworm is also known to be present on Hoosfield, which may be sampled in 1955.

Observations on the Winchester farm of Mr. P. R. J. McMorland have shown a five-fold population increase under Herta barley, a decrease to one-fifth under linseed and a comparable decrease under cocksfoot, which, although technically a host, is apparently not an efficient one. In fallow pots of infested soil the density of larvae within cysts fell (owing to hatching) by 75 per cent from March to July, and a further 4 per cent from July to October.

The experiment at Stoke-on-Tern involving sixty-four microplots has satisfactorily come through its first complete year; the object is to see the effect, on a fairly uniform and low eelworm population, of growing oats, wheat, barley and rye, both autumn and spring sown, with and without fertilizers. Also in Shropshire, several commercial fields are under observation, in co-operation with Mr. H. C. F. Newton, to follow the population fall when heavily infested soils are put down to leys or non-host crops.

Heterodera rostochiensis

Solanum demissum has been used as a convenient (because small) host plant in a study of population increases in soils initially at five known levels, established with counted cysts of graded size. There was no obvious effect of level on size of plant. (J. J. Hesling.)

Host–Parasite Relationships

Host-ranges and resistance

Host-range tests in soils infested with five species of *Meloidogyne* are continuing in electrically-heated glasshouse beds; these beds get infested with parasitic fungi, and the electrical heating wires become corroded, necessitating frequent renewals. (M. T. Franklin and A. R. Forster.)

No morphological criteria being available for most of the biologic races of stem eelworm, host-range tests are essential. Such tests indicate that the East Anglian carrot race is a population of the oat race, for, although it produces symptoms in *Vicia faba* like those due to the so-called " giant race ", it is not of that race. It has been confirmed that the only alternative host of many tested

(mainly legumes) for the lucerne race is alsike clover. Of lucerne varieties Grimm is seriously attacked, while De Puits produced a good stand in spite of being attacked. The American resistant varieties are unsuited to our conditions. (J. B. Goodey.)

In collaboration with the National Institute of Agricultural Botany, investigations into the varietal susceptibility of oats to the stem eelworm have continued, both in pot tests and in field trials in co-operation with the National Agricultural Advisory Service. It is confirmed that the spring variety Milford, and the winter varieties Grey Winter, Avoine d'hiver, Picton and S.172 are highly resistant but not absolutely so. It is hoped that further routine testing of oat varieties will be undertaken by the National Institute of Agricultural Botany and oat breeders. (J. B. Goodey.)

The pot tests of resistance of oat and barley varieties to *Heterodera major* mentioned last year were inconclusive. These pots had been inoculated with dried cysts, from which larvae are now known to hatch with difficulty. The tests have therefore been repeated using naturally-infested soil. (J. J. Hesling.)

Solanum nigrum shows a partial resistance to *Heterodera rostochiensis* in that the roots are readily invaded by larvae, which, however, fail to become mature. Repetition of an experiment reported in 1951 and 1952 has shown interesting results from exposing seedlings of *S. nigrum* and tomato (a normal host) to soil containing 0, 5, 30 and 180 larvae g., testing root-diffusate (R.D.) production at 1, 2, 4 and 8 weeks, then weighing root-systems and examining them for contained eelworms. R.D. production in the tomatoes was more seriously impeded by high densities of inoculum than was that in *S. nigrum*, in which infestation caused the peak of R.D. production to be postponed. Stunting of plants at high inocula, was more severe in tomatoes. (C. C. Doncaster.)

It seems likely that the different degrees of resistance shown by solanaceous species to *H. rostochiensis* are biochemical in nature, either by roots of susceptible species containing a factor essential to the parasite or by roots of resistant species containing an inimical factor. In either case it is possible that the factor is elaborated in the aerial parts of the plant. If so, grafting before infestation might contribute information, if the graft conferred on the stock-root system the factor normally lacking. A preliminary series of grafts has been made using tomato, potato and *S. nigrum* and including self-grafts (tomato on tomato; *S. nigrum* on *S. nigrum*), to control any physiological disturbance due to the grafting process, and transplanting to soil infested with *H. rostochiensis*, after the grafts were established. The result so far is that each root-system behaved normally, without showing any noticeable effects from the scion; thus, tomato roots became infested and *S. nigrum* roots did not, irrespective of scion. (A. R. Forster.)

Pathogenicity

In 1953 a pot experiment was set up at the Connecticut Agricultural Experiment Station to ascertain whether *Heterodera tabacum* had detectable pathogenic effects on tobacco plants. Plants were exposed to a geometric series of inoculum densities, with and without fertilizers. Using as criteria the heights of plants at various times and the final weight of tops, there was an inverse correlation between

log density and height or weight, which in no case departed significantly from rectilinearity. An interesting feature was that, at the lowest density (50 larvae/g. of soil) among the fertilized plants, plants were slightly taller and heavier than in the controls. (Dr. B. F. Lownsbery and B. G. Peters.) Strictly comparable data for *H. rostochiensis* not being available, a similar experiment with potted potatoes has been carried out this year, but at lower densities (lowest about 2 larvae/g.). A comparable inverse relationship has been found between log density and height. Numbers and weights of tubers produced, though complicated by an attack of blight, showed a similar relationship, and for all criteria the lower inoculum densities gave taller plants and more and heavier tubers than did the uninfested controls. (B. G. Peters.)

In a somewhat similar experiment with *H. cruciferae* and potted plants of Brussels sprouts, starting at a minimum density of 5 larvae/g. of soil, there was again a stunting effect from high densities and again a slight stimulating effect from low densities. The fact that stunting was significant at 125 and 625 larvae/g. suggests that this eelworm may have pathological effects on the host under agricultural conditions, a matter on which there has been some doubt. (C. C. Doncaster.)

Another host–parasite situation in which it has never been established that the host suffers significant damage is root-knot on lettuce. In a complex pot experiment three varieties of lettuce were infested with three species of *Meloidogyne*, each at two levels. A pilot test had indicated suitable levels of inoculation and times of observation. Plants were inoculated at 2 weeks of age and were lifted at five different times, when the criteria measured were: weight of tops and roots, number of galls and number of eelworms within the roots (giving also eelworms/g. of root). The data have not been fully analysed, but it is obvious that pathological effects, if any, are very slight, even at inoculation densities of 1,000 larvae per seedling. The varieties tested are of low susceptibility, at least at the relatively low temperatures at which lettuces are grown. (M. T. Franklin and A. R. Forster.)

Preliminary investigations have been made into a serious and rapid decline in mushrooms, frequently associated with the presence of species of *Rhabditis*. These eelworms are usually saprophagous rather than parasitic, and the nature of the association is of interest. Work is continuing on the association between *Hoplolaimus uniformis* and conifer seedlings, in conjunction with the Chemistry Department's investigations on nutritional problems in forest nurseries. (J. B. Goodey.) A curious intervenal chlorotic marbling has been observed in the leaves of cabbage plants which were both infested with *H. cruciferae* and inadequately fertilized. (C. C. Doncaster.)

Root Diffusate Problems

The production and storage of large quantities of active potato root diffusate present problems. It has been found satisfactory to grow Arran Banner in 6½-inch pots of unsterilized loam plus one-quarter of sand in a cool greenhouse. Leaching so as to yield 200 ml./pot can proceed twice a week from break-through for 6 weeks, and by successive plantings collection is maintained for 5 months

from early May. Loss of activity by storing at 2–3° C. is very variable, and for experimental purposes the bulk storage of one main stock is being attempted. (E. Widdowson.)

The tripartite Agricultural Research Council project continues. Professor R. H. Stoughton (Reading) produces the root diffusate; Professor A. R. Todd (Cambridge) works at its chemical analysis; D. W. Fenwick monitors the Reading samples and bio-assays various Cambridge fractions. This year has seen two major developments at Reading. First, it has been found that potatoes grown in soil in the new outside frames produce a far more active diffusate than potatoes or tomatoes grown in soil-less culture under glass. Secondly, the resulting diffusate is much more efficiently concentrated by partial evaporation under reduced pressure than by charcoal extraction. It seems likely that Cambridge can now be given adequate quantities of the active material. (D. W. Fenwick.)

The action of root diffusate from a growing crop and of other factors regulating the hatching of *H. rostochiensis* larvae is being investigated. After charging shallow 10-inch pans of infested sand with root diffusate at a central charging point and leaving the pans for varying times, cysts were recovered from annular samples of sand. The rate of cyst-emptying, revealed by counts of residual eggs and larvae still within the cysts, varied directly with time and inversely with radial distance from charging-point. This basic technique will be used to investigate the effects of temperature, soil type, etc. (E. Widdowson.)

Experiments and techniques based on the hatching of Heterodera larvae in root diffusates commonly make use of counted or weighed batches of cysts. Work is now in progress on hatching from eggs previously removed from cysts. The different rates of sedimentation of eggs and larvae in water may upset efficient sampling, which can be restored by agitation with a slow air-stream while the sample is being removed. Hatching from eggs, rather than cysts, yields the same type of curves for hatch log time and hatch log dilution of diffusate. Soaking of cysts in water, for up to 12 days, before adding diffusate, results in improved hatching; but a similar pre-soaking of eggs removed from dry cysts almost inhibits subsequent hatching unless the volume of water for pre-soaking is greatly reduced. Work is not yet sufficiently advanced to suggest an explanation of this curious phenomenon. (D. W. Fenwick.)

Eelworm Physiology

Several attempts to render *H. rostochiensis* bacteriologically sterile without killing them have failed. It has now been found that their eggs, sterilized in hydrogen peroxide (at 20 vol. concentration), can be subsequently hatched in root diffusate. A new Warburg respirometer has been calibrated, and a programme of work on the fundamental physiology of this species is now under way. (D. W. Fenwick.)

Chemical (and Other) Control Methods

In a small-scale warm-water treatment of violet plants infested with *Aphelenchoides fragariae*, bundles of eight plants were plunged

first into warm and then into cold water before re-planting. Temperatures and times were :

112·5° F. for 10 and 15 minutes.
115° F. for 8, 10 and 12 minutes.
117° F. for 6 and 9 minutes.

Living parasites were found only in the controls, and slight damage to the plants was found only after 112·5° F. for 15 minutes. (M. T. Franklin.)

Pot tests

A number of halogenated hydrocarbons have been tested in glazed pots holding 20 lb. of soil infested with *Heterodera rostochiensis*. Hatching tests on cysts recovered from samples taken 4 weeks after injection show that, of materials tested, only allyl bromide at 1 ml./pot gave results comparable with Shell "DD Mixture". In another series of tests several isothiocyanates were used, dispersed in water and sprinkled over the soil spread out in a tray; at least one of these was promising, but of doubtful practical value owing to the difficulty of application. Last year an experiment was referred to in which DD was injected into infested soil in boxes made up of 2-inch-deep sections, enabling the viability of larvae to be determined according to depth in the soil; this showed that DD lost efficacy in the upper (and lower) levels owing to excessive ventilation, a loss only partially mitigated by using a seal of water or loosely-applied foil. At the dosage used, only 1·5 per cent of larvae survived treatment in the middle layers, but 68 per cent survived in the top 2 inches. This loss, which is probably comparable with what occurs in field injections, goes far to waste the efficacy of an inherently good nematicide. This year a similar experiment has been run to test the effect of treating the upper soil layer by drenching with a dispersion in water of *para*- and *meta*-cresols, solubilized with "Teepol" according to the technique of Mr. L. N. Staniland. Results show that this drench gives an excellent kill in the surface layer and, when combined with a DD injection, there is no interaction between the two at any depth-level, the whole box of soil being adequately disinfested. Such a double treatment might well be practicable in glasshouse soils, where *H. rostochiensis* continues to be a problem. (B. G. Peters.)

Field test

Near Wisbech a 6-year field-scale, DD experiment, in co-operation with Shell Chemicals Ltd. and the West Norfolk Farmers' Manure Co., has continued. DD is being injected in some plots once only at different stages of a five-course rotation free from potatoes, and in other plots injected in the first 2, 3, 4 and 5 years. The behaviour of the *H. rostochiensis* population under these treatments is being followed. This autumn the usual soil samples have been taken (to test the results of the third-year injections) and the fourth-year injections have been given. Next autumn the final (fifth) injections will be given and, in 1956, an indicator crop of potatoes will be grown. As anticipated in the last Annual Report (p. 102), plots injected in 1952 only, for which a poor kill was

recorded from soil samples of spring 1953, nevertheless showed a good kill in the samples of autumn 1953. In view of the curious unreliability of spring samples from this silty soil, they have now been dropped. This long experiment is now beginning to yield interesting results. (B. G. Peters, C. C. Doncaster and J. J. Hesling.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

During the current year F. Last was transferred from the Plant Pathology Department to work on fungicides, R. van Baer from Australia joined the department as a temporary worker, and M. Jeremić and R. Vujadinović from Yugoslavia arrived for a stay of 6 months. Other people who have stayed for short periods are R. J. A. W. Lever, from Malaya, and M. H. Hassanein, from Egypt. C. Potter attended the International Union for the Protection of Nature in Copenhagen at the request of the Society for the Promotionof Nature Reserves. He presented a paper on " The action of insecticides on insect populations in England ".

Physical Chemistry

A. H. McIntosh and Margaret Macfarlane have continued their work on particle size and toxicity of suspensions of contact insecticides.

In recent years they have carried out tests to show the effect of physical properties on the difference in toxicity between two forms of a single poison—colloid and crystals. This has involved, with each of nine DDT analogues, measurements of: (*a*) retention of insecticide by adult *Oryzaephilus surinamensis* L. from each type of suspension applied; (*b*) rate of crystallization of deposits from colloidal suspension; (*c*) solubility of insecticide in oil; (*d*) rate of solution of crystals in oil. This work has been extended and finished, and is now being published.

If the toxicities of two forms of the same insecticide are compared on one insect species at different after-treatment temperatures, the relative toxicity of the two forms often depends on temperature. We think that it is possible to foretell whether the relative toxicity will increase or decrease when the after-treatment temperature is, for example, lowered. We are now carrying out experiments to test this point, using as many insect species and as many types of insecticide as possible. This work is not complete.

Biochemistry

Investigations on the mode of action of organophosphorus insecticides, begun in earlier years by K. A. Lord and C. Potter, have been continued and extended during the past year.

Work reported in previous years on the comparison of a group of phosphorus insecticides and their potency as inhibitors of enzymes hydrolysing acetyl choline and phenyl acetate has now been published. One of the conclusions drawn from the inhibition data was that both types of enzyme activity derived from *Tenebrio molitor* L., *Blattella germanica* L., *Tribolium castaneum* Hbst. and *Dysdercus fasciatus* Sign. differed from species to species. By using paper electrophoresis this has now been confirmed for the soluble enzymes

which hydrolyse phenyl acetate. Paper electrophoresis also indicated that the enzyme preparations sometimes contained more than one enzyme which hydrolysed phenyl acetate, under the conditions used for the electrophoresis experiments.

Three substrates were investigated for use in locating the enzymes on paper: (*a*) fluorescein acetate, a colourless, non-fluorescent material which on hydrolysis gives rise to fluorescein which is strongly fluorescent; (*b*) indoxyl acetate, which when hydrolysed liberates indoxyl, which in the presence of air gives rise to indigo blue, a deep-blue dye; (*c*) phenyl acetate. The phenol liberated on hydrolysis was detected by coupling, in alkaline conditions, with diazotized *p*-nitro-aniline. The chromogenic substrates were sprayed on to the wet papers in solution in benzene. Other solvents, either more or less volatile or water soluble, did not give such consistently good results. Fluorescein acetate and indoxyl acetate are simpler to use than phenyl acetate, since, in each case, the product of hydrolysis becomes visible without additional treatment. However, since the substrate specificity of the enzymes is not known, it was considered worth while to compare the results obtained using these two substrates with those using phenyl acetate.

Insect enzymes which hydrolyse acetyl choline have proved more difficult to study by electrophoretic methods than the more soluble enzymes which hydrolyse acetyl choline. Some progress has, however, been made; the enzyme from *B. germanica* has been largely brought into solution by the use of sodium taurocholate, and some purification of the enzyme has been effected by dialysis and ammonium sulphate fractionation.

Preliminary tests have been carried out on 3-(diethoxyphosphinyloxy)-*N*-methyl-quinolinium methyl sulphate (Ro 3-0422), which was kindly supplied by Roche Products. This substance is very highly toxic to mammals. An LD50 of 20 μg./kg. by intravenous injection has been reported for mice. It is a very potent inhibitor of mammalian cholinesterases. We have shown that Ro 3-0422 is also a potent inhibitor of the insect esterases hydrolysing both acetyl choline and phenyl acetate. The substance is, however, not a very potent insecticide, and failed to give a significant kill when injected at the rate of 40 mg./kg., into *B. germanica* or *T. molitor*. *B. germanica* were, however, killed at twice this dosage rate. The LD50's of TEPP for *B. germanica* and *T. molitor* by topical application are 4 mg./kg. and 6 mg./kg. respectively. No definite conclusions can be drawn from these findings. Lack of toxicity to insects may be due to the way in which the substance distributes within the insect or to rapid detoxification, but the results are interesting, since they show clearly that anti-esterase activity is not necessarily a guide to insecticidal activity.

The effect of TEPP on the development of *D. oleracea* eggs has been further examined. It was found that aqueous solutions of TEPP applied to newly laid eggs killed but allowed embryonic development to occur. When eggs were placed on films of TEPP or HETP (containing less than 20 per cent TEPP) embryonic development did not occur, providing the eggs were left on the film for a minimum time (20 hours) before the TEPP was removed by washing with water containing a wetter. The shorter the exposure time, the less was the effect of the TEPP.

Examination of the esterases of both untreated and treated eggs showed that in no case was the hydrolysis of phenyl acetate completely inhibited although extracts obtained by grinding (without addition of water) mixtures of treated and untreated eggs in all cases suggested that some residues of TEPP occurred in the eggs. The residues were sufficient to give a partial inhibition of the esterases from the untreated eggs. The amount of inhibition apparent seemed to decrease with the age of the eggs. Enzymes hydrolysing acetyl choline appeared in batches of eggs in which embryonic development was not apparent except in a small proportion of eggs. It is possible that the activity may have occurred only in those eggs showing some development.

There was no apparent inhibition of the enzymes hydrolysing acetyl choline in normal eggs ground (without addition of water) together with eggs in which embryonic development had been inhibited by TEPP. In the course of these studies the high level of hydrolysis of phenyl acetate by extracts of *D. oleracea* eggs at all stages of development and the increase of hydrolysis of acetyl choline as the egg develops (previously reported) has been fully confirmed.

From this work it appears that TEPP only penetrates the chorion of *D. oleracea* fairly slowly, and other species which might have more permeable shells are being examined.

The development of enzymes hydrolysing acetyl choline and phenyl acetate in insect eggs has now been examined in two further species. As in the case of *D. oleracea*, the hydrolysis of acetyl choline becomes evident in the eggs of *Pieris brassicae* only a considerable time after the eggs are laid, and then increases until the eggs hatch. The hydrolysis of phenyl acetate is evident immediately the eggs are laid, and remains at a high level throughout the development of the egg. An attempt has been made to correlate embryonic development with the hydrolysis of acetyl choline by extracts of eggs of *P. brassicae*. An apparently anomalous result has been obtained with *Dysdercus fasciatus*. So far it has not been possible to demonstrate the hydrolysis of acetyl choline by extracts of eggs of *D. fasciatus* at any stage of development, although extracts of the adults and of all stages of the nymphs hydrolyse acetyl choline. Phenyl acetate is rapidly hydrolysed by extracts of eggs of these species at all stages of development.

Work on the action of organophosphorus insecticides inside a plant mentioned in last year's Report has been prepared for publication. The evidence obtained suggests that some organophosphorus compounds can have an effect on plant enzymes *in vivo*. Further work is necessary to elucidate this problem fully.

Organic Chemistry

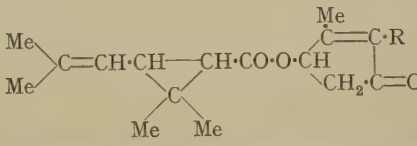
The relationship between insecticidal activity and chemical constitution in compounds related to the pyrethrins

The compounds being studied by M. Elliott are related to the naturally occurring pyrethrin I

$$(\text{I, R} = \textit{cis}\text{-}CH_2{\cdot}CH{=}CH{\cdot}CH{=}CH_2)$$

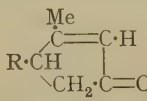
and cinerin I (I, R = *cis*-$CH_2{\cdot}CH{=}CH{\cdot}CH_3$). Work has been

carried out recently to try to throw light on the part played by the side chain R in (I) on the toxicity of the compounds. In



(I)

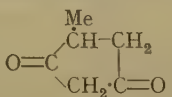
particular, the ester (I, R = H) has been prepared from (II, R = H) and the usefulness of the latter compound as an intermediate in the



(II)

preparation of insecticidally active esters has been examined. The work carried out with (II, R = H) is summarized below.

3-Methyl-*cyclo*pent-2-enone (II, R = H), now available by the cyclization of acetonyl acetone (Acheson & Robinson, *J. chem. Soc.*, 1952, p. 1127), had been obtained, prior to this publication, by the cyclization of ethyl acetonyl acetoacetate by Elliott in this laboratory. Reaction with *N*-bromosuccinimide gave 4-bromo-3-methyl-*cyclo*pent-2-enone (II, R = Br), which with silver acetate produced the acetoxy compound (II, R = O·Ac). Since Conia (*Bull. Soc. chim. France*, 1954, 690) showed that *iso*phorone was alkylated by allyl chloride in the presence of sodium *t*-amylate to give 2-allyl-3 : 6 : 6-trimethyl-*cyclo*hex-2-enone, the possibility of obtaining an analogous sodium salt from (II, R = O·Ac) was investigated. However, this reaction did not occur, since with sodium, sodium hydride and alcoholic sodium ethoxide cleavage of the ester grouping occurred, both in (II, R = O·Ac) and with (II, R = (±)-*cis-trans*-chrysanthemyl—see below). From the latter compound, only (±)-*cis-trans*-chrysanthemic acid could be isolated. In 5 per cent aqueous sodium hydroxide (II, R = O·Ac) showed $\lambda_{max.}$ 2230 Å., $\epsilon_{max.}$ 10,950; after heating to 100° for 30 minutes, $\lambda_{max.}$ was at 2590 Å., $\epsilon_{max.}$ 15,500. This spectral evidence indicated that, after saponification, the αβ-unsaturated γ-ketol system in (II, R = OH) had been isomerized to one or both of the enolic forms of the 1 : 3-diketo-*cyclo*pentane (III). (It is probable that an



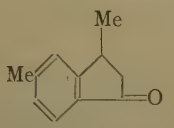
(III)

analogous isomerization of naturally derived pyrethrolone and cinerolone takes place when the so-called "*iso*-pyretholone enols" are formed, of which the structure has not been determined.) Such re-arrangements would preclude the alkylation in the 2-position of esters such as (II, R = O·Ac) under alkaline conditions.

It was necessary to prove that 3-methyl-*cyclo*pent-2-enone was brominated in the 4-position in reaction with *N*-bromosuccinimide, so that the structure of the compound obtained by reaction of the

bromide with silver (±)-*cis-trans*-chrysanthemate would be known to be (I, R = H). Other possible sites for attack were the 5-position and the methyl group. The former was unlikely from previous experience of the reactivity of the *cyclo*pent-2-enone ring with *N*-bromosuccinimide. If bromine had replaced a hydrogen atom of the 3-methyl group, hydrogen bromide could not be easily evolved under mild conditions. It was found that the brominated product evolved hydrogen bromide at room temperature on treating with trimethylamine in carbon tetrachloride. The product was expected to be 3-methyl*cyclo*penta-2 : 4-dienone. The latter compound had been described by Pavolini, Gambarin and Verza (*Ann. Chim., Roma* (1952), **42**, 149) as an easily polymerizable yellow liquid b. p. 218–220°, n_D 1·501.

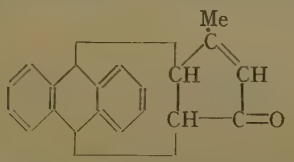
Assuming that the initial stages of the synthesis proceeded as described by Pavolini *et al.*, it seemed probable that the product was 3 : 5-dimethylindanone (IV) (or the isomeric 3 : 6-dimethyl com-



(IV)

pound) rather than 3-methyl*cyclo*penta-2 : 4-dienone. The product obtained by Pavolini *et al.* was characterized only by its refractive index, density, boiling point and carbon–hydrogen analysis. An oxime m.p. 143–145° was prepared, but no analytical figures were quoted for it.

The synthesis was therefore repeated and the Italian findings confirmed up to the last stage. However, when (V) was heated



(V)

above its m. p., carbon monoxide was detected in the evolved gases, and the product and its 2 : 4-dinitrophenylhydrazone had analyses and ultra-violet absorption spectra in agreement with those of a derivative of 3 : 5-(or 3 : 6-)dimethylindanone. It was concluded therefore that the product prepared here under the conditions used by the Italian workers was not 3-methyl*cyclo*penta-2 : 4-dienone but a dimethylindanone.

The dimethylindanone obtained by the anthracene route and its 2 : 4-dinitrophenylhydrazone were not identical with authentic 3 : 6-dimethylindanone, which was obtained by pyrolysis of the product from dehydrobromination of (II, R = Br). The infra-red spectra indicated only minor differences between the two ketones, however, and further work to determine the nature of the difference is in progress.

It was concluded that, first, the ease of elimination of hydrogen

bromide from (II, R = Br) gave the required proof of its structure and thence of (I, R = H), and, secondly, the claims of Pavolini *et al.* to have prepared 3-methyl-*cyclo*penta-2 : 4-dienone could not be substantiated.

The compound (I, R = H) had negligible insecticidal activity, in contrast to (I, R = allyl), which is highly toxic. It was prepared and tested with a series of other esters derived from (I) that had varying side chains and on which the insecticidal results will be summarized in next year's Report.

Toxicity and Persistence of Insecticidal Deposits

This work has been continued by J. Ward and Eileen M. Gillham. The previous work has been reported in two papers which have been submitted to the *Bull. ent. Res.* for publication.

The rate of evaporation of various insecticidal deposits was studied by exposing sprayed petri dishes in a constant-temperature room (29° C.) in which the air was kept moving by a fan. The deposits were shielded from bright light. Under these conditions, a crystalline deposit of DDT at the rate of 4 μg./sq. cm. evaporated almost completely in 2 weeks. Arochlor resin, which has been shown to decrease the rate of evaporation of BHC, does not prolong the life of DDT residues under the conditions of this test.

The persistence of the bromine analogue of DDT, 1 : 1-*bis*-(*p*-bromophenyl)-2 : 2 : 2-trichloroethane, was compared with that of DDT in the constant-temperature room and was found to be much greater, a deposit of 1 μg./sq. cm. decreasing by only 25 per cent in 19 days, while a similar deposit of DDT decreased by 96 per cent. Previous reports of the toxicity of the bromine compound are conflicting, so it is being tested in comparison with DDT against several species of insect.

The effect of sunlight on three different types of DDT deposit (pure *pp'*-DDT, commercial DDT and a liquid deposit of DDT and Arochlor resin) was studied by exposing sprayed petri dishes to direct sunlight and to sunlight filtered through window-glass to block out short ultra-violet radiation; the temperature and degree of ventilation of the two batches of dishes were the same. After 3 days' exposure, totalling about 24 hours of sunshine, the *pp'*-DDT had diminished by about a quarter of the amount originally present, while the deposits of crude DDT and of DDT with Arochlor had each lost about half. Losses from the dishes exposed to direct sun and to sun screened through glass were about the same. Weather conditions made it impossible to study the effect of longer exposure periods.

The contact toxicity to *T. castaneum* of liquid deposits of DDT and Arochlor resin has been measured. It has been found that under certain circumstances the liquid deposits can be several times more effective than the crystalline, when equal weights of DDT per sq. cm. are compared. When the DDT is applied as a measured drop, the addition of Arochlor resin causes a slight reduction in the toxicity, so the enhanced contact effect is presumably due to increased pick-up by the insects, and not to improved penetration of the cuticle or to a synergistic action of the Arochlor resin.

Bio-assay

Insecticidal activity of N-iso*butylcarboxyamides*

M. Elliott and P. H. Needham have carried out tests of some further compounds of this type, continuing the work mentioned in the Report of Rothamsted Experimental Station for 1952 to assist Dr. L. Crombie (Organic Chemistry Department, Imperial College of Science and Technology). The bio-assay tests were performed on *Tenebrio molitor* L. by a measured-drop technique previously described.

The following results were obtained :

Compound	Structure	% kill at 3% w/v in acetone
Anacyclin [1]	$CH_3(CH_2)_5C{\equiv}C{\cdot}C{\equiv}C(CH_2)_3CH{=}{}^{t}CH{\cdot}CH{=}{}^{t}CH{\cdot}CO{\cdot}NH{\cdot}CH_2CH(CH_3)_2$	6
Tetrahydro-anacyclin [1]	$CH_3(CH_2)_5CH{=}{}^{c}CH{\cdot}CH{=}{}^{c}CH(CH_2)_3CH{=}{}^{t}CH{\cdot}CH{=}{}^{t}CH{\cdot}CO{\cdot}NH{\cdot}CH_2CH(CH_3)_2$	100
Pellitorine [1, 2, 3]	Distilled sample isolated from *Anacyclus pyrethrum* D.C. (Pellitory).	100
*N-iso*butyl dodeca-*trans*-2 : *trans*-4-dienamide	$CH_3(CH_2)_6{\cdot}CH{=}{}^{t}CH{\cdot}CH{=}{}^{t}CH{\cdot}CO{\cdot}NH{\cdot}CH_2CH(CH_3)_2$	6

[1] Crombie, *Nature, Lond.*, 1954, **174**, 832.
[2] *idem*, *J. chem. Soc.*, 1952, 4338.
[3] *idem*, *J. chem. Soc.* (in the press).

A group of amides derived from deca-2 : 4-dienoic acid was available from Dr. Crombie, and an insect susceptible enough to enable their insecticidal activity to be compared was sought. This would enable information about the effect of the amine portion of the molecules on activity to be obtained. However, *N-iso*butyl-dodeca-2 : 4-dienoic acid gave such very low kills when applied topically to *Megoura viciae* and *Phaedon cochleariae* that further tests were abandoned.

Insecticidal activity of organo-phosphorus compounds

The series of experiments started last year has been continued by P. H. Needham. In addition, he has carried out some experiments in which the systemic action of " Systox " and " iso-Systox " has been tested in several ways against the aphid *Megoura viciae*. An attempt has been made to assess separately the contact and fumigant action, as well as the toxicity to feeding aphids, of leaves from broad-bean plants which have taken up through their roots 20 ml. of solution of the insecticides mentioned. A concentration of either " Systox " or " iso-Systox " required to produce just 100 per cent mortality of feeding aphids was found to exhibit no fumigant action through the leaves. The surface of these leaves did not kill by contact action aphids with severed mouth parts.

Bio-assay techniques

Methods of bio-assay of residual films were examined by Eileen M. Gillham and J. Ward in connection with the work on the persistance of insecticidal deposits. An attempt was made to use the Mustard Beetle, *Phaedon cochleariae* Fab., as an alternative test insect to *Tribolium castaneum* Hbst. It was not found possible to obtain reproducible results with the Mustard Beetle, so work with

it was discontinued. A method of test using *Drosophila melanogaster* Meig. has been evolved, but so far it has not been used with DDT deposits.

A. H. McIntosh has observed that when adult *Tenebrio molitor* L. are sealed up in a small volume of air without any insecticide, they become paralysed in about 24 hours. The exact time depends on the degree of crowding; it decreases as the crowding increases. If the paralysed insects are now allowed a plentiful supply of air, they recover in an hour or so. If they are sealed up again they do not become paralysed again, however long they are kept. It is assumed that the paralysis is due to poisoning by carbon dioxide, and that the insects become "conditioned" to it (cf. Report of Rothamsted Experimental Station for 1953, p. 109, and below).

This type of paralysis may upset the results of laboratory tests of insecticides as fumigants, and may also interfere with other tests if insufficient aeration is allowed.

Pyrethrum

Synergism

The work on the study of synergism of the pyrethrins has been continued by Daphne Holbrook, K. A. Lord and C. Potter. *T. molitor* has so far proved to be the most successful test insect, and the results obtained with three synergists (piperonyl butoxide, Sulfoxide and *Melaleuca bracteata* oil) have been confirmed and subjected to probit analysis. This analysis shows that piperonyl butoxide and Sulfoxide have similar synergistic properties. The probit lines for these two compounds were roughly parallel at the various concentrations. Whereas with *Melaleuca bracteata* oil the probit lines converged at the LD75–LD100 levels.

It is intended to repeat this work with another test insect—the housefly, *Musca domestica*, when these insects have been reared in sufficient numbers.

The constituents of pyrethrum flowers

An automatic fraction collector for the chromatographic work on the separation of the constituents of extract of pyrethrum flowers was built by A. J. Arnold and brought into use by J. Ward in July. The degree of separation obtained under various conditions was studied, using purified and decolorized extracts. Attempts to use finely-ground alumina as a packing for the chromatographic column instead of the standard 100–200-mesh material were not successful, owing to the difficulty of obtaining uniform packing of the columns. The very low rates of percolation made possible by the use of the automatic fraction collector resulted in an improved separation. Work has begun on the examination of the constituents, both insecticidal and inert, of crude extracts of pyrethrum flowers.

Insect Resistance to Insecticides

F. Tattersfield and Jill R. Kerridge have continued their work on this subject. *Drosophila melanogaster* has been used, so far, as test subject, and it has been shown that by a process of selection resistant strains can be obtained, but some attention has necessarily been given to factors other than selection.

The problem of conditioning

The strain of *Drosophila* which was used for selection work developed a susceptibility to carbon dioxide, from which highly resistant strains could be readily obtained by selection. In addition, however, this strain showed the property of becoming more resistant if treated with sublethal doses of carbon dioxide given in two ways : (*a*) by administering pure carbon dioxide for different periods of time, short enough so that, on the average, little or no lethal effect was produced, and on recovery subjecting them to more prolonged periods, comparisons with fresh untreated insects being made; (*b*) by administering non-lethal dilutions of carbon dioxide in air, but increasing concentrations stepwise, and later submitting to pure carbon dioxide for various periods of time, and the lethal effect being compared with fresh untreated insects.

(*a*) It was found that for a short period after the administration of pure carbon dioxide for a few seconds, very susceptible flies became highly resistant for a short period of time. With less susceptible flies the resistance persisted for a longer period. Thus, in one experiment 24 hours after conditioning all the survivors of the treatment for 7·5, 15, 30 seconds were immune to a treatment of 600 seconds, and counting all those dying during conditioning, 75 per cent survived against a survival of 44 per cent with fresh insects. This result was significant.

(*b*) Conditioning with increasing concentrations of carbon dioxide in air for different exposure times yielded similar results. The data were analysed by ourselves, and by M. J. Healy by a different technique, and similar conclusions drawn :

(i) The average proportion surviving in the " conditioned " insects is significantly greater than that with " fresh " insects.
(ii) There is a slight tendency for the proportion surviving to increase with increasing time of exposure during " conditioning ".
(iii) There is a definite tendency for the proportion of survivors to increase with increasing time of exposure to 100 per cent carbon dioxide. (This is not easy to understand, unless it is explained by the possibility that, when passing the carbon dioxide over insects, it takes time to replace the air, during which the insect is being " conditioned " and its survival prolonged.)

Conditioning experiments with DDT and BHC

Some recent experiments suggest that a resistant strain of *Musca domestica*, having lost some of its resistance, might have it restored by conditioning. The testing of such a hypothesis would require appropriate insects. It was considered advisable to carry out a series of trials to ascertain whether a normal culture of insects (*Drosophila melanogaster*) could be conditioned, either positively (i.e., towards greater resistance) or negatively (towards greater sensitivity), and whether one or other of these effects was handed on to their progeny.

Reliance in the main had to be put on the females, as the males are more sensitive, and when segregated may die out during the tests.

In two series in which the conditioning spraying ranged from 0·0025 to 0·01 per cent in three and four stages, there was a slight

decline in resistance after conditioning as judged by the value of *m* in the log median lethal concentration, but there was a decline in slope of the regression line, indicating a more pronounced effect on the less resistant insects, so that, judged at a kill of about 90 per cent, the effect is almost nil.

There is, however, very considerable difficulty in allowing for deaths during conditioning, when conditioning is started at a low and succeeded by higher concentrations. On reversing the process, and starting conditioning at the highest concentration 0·01 per cent DDT followed by 0·005 per cent and 0·0025 per cent, the log median lethal concentrations run in declining order, untreated insects > insects treated once > insects treated three times, showing a decline again in resistance with conditioning, *but* there is an *increase* in the slope of the regression line with conditioning, indicating that the more resistant portion of the population is being relatively more affected than the less resistant portion.

Tests with the medium only showed that there was no significant difference between the value of the median lethal doses between fresh insects and those sprayed once and three times, but that one spraying increased the slope of the regression line, and three slightly lowered it.

A number of experiments were carried out to ascertain the effect upon the progeny of the conditioned insects. With the females, after five conditioning sprays with concentrations of DDT that showed little if any selective power, the resistance declined significantly, but where the concentrations had been high enough to show selection (over 90 per cent kill) resistance increased significantly. With the males subjected to five conditioning sprays, the final tests upon the male progeny showed a slight but not significant rise in resistance; but where the treatments had given rise to a kill, likely to be selective (about 90 per cent), the resistance of the male progeny had increased significantly.

Our experimental results did not show, when judged at the median lethal dose, that the resistance of adult *Drosophila melanogaster* could be increased either in parents or progeny by conditioning with sub-lethal doses of DDT.

Experiments carried out with benzene hexachloride were less exhaustive, but the results obtained indicated that this conclusion was true of this insecticide also.

Work has been started to test the effect of different food media upon susceptibility to DDT and BHC, and interesting preliminary results have been obtained of the bearing this factor may have upon the reproduction, both in numbers and size of the progeny, as well as upon resistance to insecticides.

It is now proposed to repeat the work with greater care, since we have found that the adults carry yeasts on their bodies, and this food has considerable bearing upon the results obtained. With the help of F. Last, considerable headway has been made on a suitable technique for obtaining yeast-sterile adult *Drosophila*.

Insect Rearing

Thirty-one species of insect have been reared during the year, fifteen plant feeders and fourteen stored-product insects, together with *Drosophila melanogaster* Meig. and *Musca domestica* L.

Of these, five species have been discontinued and six are new to last year's list. The new species are the bird-cherry aphid *Rhopalosiphum padi* L., the cabbage root fly *Hylemyia brassicae* Bouché, the large cabbage white butterfly *Pieris brassicae* L., the American cockroach *Periplaneta americana* L., the house cricket *Gryllus domesticus* L. and the housefly *Musca domestica* L.

Joyce Kenten has written up her work on the factors influencing the production of the various forms of the aphid *Acyrthosiphon pisum* Harris, and it has been accepted for publication.

Most of the experimental work on rearing techniques, including diapause, has been done on the wheat bulb fly *Leptohylemyia coarctata* Fall. and is described in the next section, together with the other work on this species.

Joyce Kenten has done a considerable amount of work on the embryological development of *Pieris brassicae* in connection with studies of the action of organo-phosphorus compounds on insect eggs.

Control and Laboratory Rearing of *Leptohylemyia coarctata* Fall., the Wheat Bulb Fly

Work on the wheat bulb fly (*Leptohylemyia coarctata* Fall.) included laboratory, box and field experiments on insecticidal control, and studies on laboratory rearing of the insect. M. J. Way, R. Bardner and Joyce Kenten have collaborated on this work.

Studies on the action of insecticides

(a) *Laboratory experiments.* 2nd and 3rd instar larvae were collected in the field and a dipping technique was used to treat them with different insecticide emulsions. The larvae were kept at 20° C. after treatment and mortalities recorded after three days. The order of toxicity was dieldrin = endrin < parathion < aldrin < γ-BHC < DDT < chlordane.

(b) *Seed-box experiments.* Wheat was grown outdoors in seed-boxes containing known numbers of wheat bulb fly eggs and various formulations of insecticides. Dusts "drilled" with the wheat seed included 2 per cent γ-BHC at 3 g. dust per foot of drill, and 2 per cent dieldrin and 2 per cent demeton ("Systox") at 4 g./foot. All gave good control of attacking larvae, especially γ-BHC and demeton. Seed dressings (containing 70 per cent active ingredient) of γ-BHC at 0·4 g. dressing per 100 g. wheat, and dieldrin at 1 g. dressing per 100 g. wheat were less effective. An interesting effect was observed with the dieldrin treatments, in which the larvae attacked and damaged the first tillers but died before damaging further ones.

This season, more insecticides, including endrin, isodrin, aldrin, DDT and parathion, are being tested as seed dressings and as dusts drilled with the seeds. A method which uses a methyl cellulose sticker for coating the seed with large quantities of insecticide has been developed. Other experiments in progress are designed to throw light on the mode of action of some of the insecticides tested last year, and on their persistence in the soil.

(c) *Field experiments.* In March small plots of wheat attacked by wheat bulb fly larvae were sprayed by hand with parathion and

demeton: 0·05 per cent parathion gave almost 100 per cent control. This result suggests that a suitable spray application in March might be a practical alternative to the ploughing up and drilling with another crop which is usually advised. This work is being followed up.

Laboratory rearing

Eggs laid during the previous summer (1953) were stored outside or at 8° C., until January and February, when they were placed in pots of wheat. These were kept under various conditions, (*a*) outside; (*b*) in a cool greenhouse; (*c*) at 20° C., and (*d*) at 8° C. 7 per cent of the eggs stored at 8° C. and 38 per cent of those stored outside, produced adult flies. It is considered that the eggs stored at 8° C. failed to produce adult flies because diapause of the egg had not been broken. Some larvae were reared individually in cut stems of wheat in specimen tubes at a constant temperature of 20° C. Under these conditions the length of the various stages was: *larval stage*—males 17–20 days, females 17–26 days; *pupal stage*—males 22–23 days, females 22–27 days. These adults emerged during March, 3 months earlier than those reared outside or in the cool glasshouse, although the eggs had hatched at the same time.

Satisfactory techniques for rearing larvae on a large scale have not yet been developed. Suitable oviposition cages have been designed. The adults were fed on a mixture of honey and condensed milk, and on mammalian blood. They oviposited freely through perforated zinc at the bottom of the cage. This method made egg-collection simple and easy, and about 15,000 eggs were obtained for insecticide testing and laboratory rearing.

The 6-month diapause during the egg stage is a disadvantage for laboratory rearing, and special attempts have been made to shorten the diapause period. Eggs were kept at constant and varying temperatures from 0° to 30° C., but none hatched until over 4 months after they were laid. The histology of the developing embryo was studied in an attempt to determine the effects of the different temperature treatments. A continuous temperature record was kept from August 1953 to March 1954 in soil containing wheat bulb fly eggs, and the time of egg hatch was related to changes in soil temperature. This year, temperatures similar to those outdoors, but more extreme, are being used in the laboratory in an attempt to reduce the period of the diapause.

Field Experiments

Control of bean aphid (Aphis fabae, *Scop.*)

M. J. Way was responsible for this work. He was assisted by R. van Baer.

(a) *Comparison of different insecticides.* This experiment was done in conjunction with the Ministry of Agriculture Plant Pathology Laboratory, Harpenden, and was made possible by Mr. F. Harvey of Bishops Stortford, who provided a field of spring-sown beans and co-operated in the spraying operations.

The insecticides were applied once only (22 June 1954) by tractor-drawn machinery. Spray nozzles on the spray boom were set over the rows of beans, with three nozzles per row, one spraying

vertically down and two obliquely down from each side of the row. The volume of spray applied was based on 100 gal./acre for a row spacing of 22 inches.

The sprays applied were all commercially formulated emulsions, except nicotine. The treatments were replicated four times, and yields of seed on some were obtained by a sampling technique which proved satisfactory. Full details are given in the following table:

TABLE 1

Insecticide used	Conc. of active ingredient, % w/v *	Approx. no. of aphids per stem at peak (26.7.54)	Seed yield, cwt./acre
Parathion	0·02	248	22·6
Malathion	0·1	238	—
Demeton (" Systox ")	0·025	50	—
" Metasystox " ..	0·05	16	24·2
Nicotine	0·05	221	25·4
DDT	0·2	668	22·9
γ-BHC	0·05	191	—
Endrin	0·05	435	—
Untreated		1589	16·7

* Except nicotine which is % v/v.

At the doses applied, demeton and " Metasystox " (the systemic insecticides) were most effective, while DDT and endrin were probably the least effective. All, however, gave useful control.

The success of the experiment suggests that some of the insecticides may still remain effective when applied through only one nozzle per row and at relatively low volume. It is hoped to test this in 1955.

(b) *Timing of spray application.* In work on *A. fabae* control, mentioned in previous Annual Reports, the insecticide was applied once only when it was considered that migration of aphids into the bean crop had just ceased. This year the movement of adult aphids from *Euonymus* to beans was studied quantitatively in relation to the time of spraying, and this will be continued in future years to check that early spraying is practicable.

(c) *General effects of insecticides.* In a field trial at Rothamsted, quantitative data were obtained on the effects of a DDT spray suspension, and a demeton spray, on insects other than the bean aphid. Most time was spent developing and comparing different insect sampling methods, including beating-tray techniques, sticky traps and removal of stems for subsequent examination in the laboratory. The DDT suspension had a relatively small effect on the *Aphis fabae* population, but was highly toxic to the pea aphid, *Acyrthosiphum pisum*, the pea and bean weevil *Sitona lineatus* (which was abundant on the experimental area) and to pollen beetles (*Meligethes* sp.). It was also toxic to Coccinellid, Anthocorid and Staphylinid predators of aphids, but did not affect oviposition by Syrphid adults or reduce the populations of their larvae.

The effect of demeton on aphid predators was complicated by its virtual extermination of aphids, resulting in loss of attraction of predators to the demeton-treated plots. Demeton had less effect than DDT on phytophagous beetles. It is hoped to continue this work in 1955.

(d) *Effect of insecticides on yield.* In the field experiment at Rothamsted the yields of seed from spring and autumn beans sprayed once on 21 June 1954 were as follows :

TABLE 2

Insecticide used	Conc. active ingredient, % w/v	Spring beans Approx. peak population, aphids/stem	Spring beans Seed yield, cwt./acre	Autumn beans Approx. peak population, aphids/stem	Autumn beans Seed yield, cwt./acre
Untreated ..	—	2772	16·8	3218	18·8
Demeton ..	0·1	48	35·5	70	28·8

It is interesting to note that in addition to showing a very large increase in yield with both spring- and autumn-sown beans the figures also indicate that spring beans may give a larger crop than autumn beans if they are kept free from aphid attack.

(e) *Nature of* A. fabae *damage.* Work was done on build-up of aphids in relation to the stage of growth of the crop. This suggested that the " setting " of the flowers is a critical stage, and if even a relatively small aphid population is at, or near, its maximum when this is occurring, serious crop loss may result. If most flowers have set while the aphid numbers are still low the subsequent increase to a large population may do relatively little harm. This may have an important bearing on the economics of aphid control.

Control of the vectors of potato virus

P. E. Burt of this department with L. Broadbent, of the Plant Pathology Department, continued their field experiments on the control of potato virus diseases.

Another experiment of a similar nature to that done in 1953 was carried out (see Report of Rothamsted Experimental Station for 1953, p. 115), but a change in the design was made which reduced the number of treatments to four. The treatments used were DDT, endrin, parathion and demeton (" Systox "), all formulated as emulsions. The apparatus and methods of spraying employed were substantially the same as in 1953, and the crop was sprayed seven times during the period 16 June to 31 August. Cold, rainy weather persisted throughout the season and aphids were few. Unlike 1953, when *Myzus persicae* Sulzer predominated, *Aphis symphiti* Schrank was the most numerous species.

Aphid control was effective with all the treatments. For example, on 13 July, the total number of aphids found on 150 leaves from the control plots was 703, of which 559 were *A. symphiti* and 95 *M. persicae*; the greatest total from any of the treated series was ten. Figures for the amount of virus spread will not be available until next year.

Further information about the result of the 1953 virus control experiments is given in the report of the Plant Pathology Department.

Control of pea weevil (Sitona lineatus *L.*)

Experiments were done in the Peterborough area by P. H. Needham and M. J. Way in co-operation with the Home Grown Threshed Peas Joint Committee to test the effectiveness of insecti

cidal seed dressings. Two types of seed dressing were used: (1) a 50 per cent dust shaken with the seed. By this method the seed would hold a maximum of 0·02 per cent of its weight of active ingredient, and this dose was used in the field experiments for γ-BHC, demeton (" Systox ") and dieldrin. (2) A method was developed whereby the insecticide was stuck to the seed with a resin " sticker " and then covered with a film of methyl cellulose. The latter stopped the insecticide flaking off the seed, and prevented operators being contaminated by it. Using this method, any dose of insecticide could be applied to the seed, the limit depending on the phytotoxicity of the chemical. Table 3 shows results of phytotoxicity tests using γ-BHC, demeton and dieldrin dressed seeds planted in

TABLE 3

Preliminary phytotoxicity tests

Treatment	% active ingredient of wt. of seed	% Germination
γBHC + coating	0·25	48
	0·063	46
	0·016	72
Demeton + coating	1·0	10
	0·25	54
	0·063	62
Dieldrin + coating	1·0	72
	0·25	86
	0·063	84
Control + coating	—	80
Control untreated	—	84

soil. Using the sticker, the doses of active ingredient for the field trials expressed as per cent of weight of seed were 0·02 per cent for BHC, 0·04 per cent for demeton and 1·0 per cent for dieldrin. Plant counts showed that these dosages were not significantly phytotoxic.

Weevil control in the field experiments was assessed by counts of feeding damage (degree of leaf notching) by adult weevils, by the amount of nodule damage caused by larvae, by counts of larvae and pupae, and by crop yield. Counts of feeding damage (Table 4) showed no significant control of adults; root nodule damage by larvae was almost 100 per cent in all plots. Preliminary larval and pupal counts showed that populations in the treatments were not obviously different from those in the controls, and seed yields

TABLE 4

Mean percentage of margin notched on the youngest and oldest fully opened leaves 6 weeks after sowing

Site	Demeton		BHC		Dieldrin		Control	
	Coated	Dusted	Coated	Dusted	Coated	Dusted	Coated	Dusted
Wansford ..	98	98	98	99	99	98	99	98
Crowland ..	40	43	50	32	38	46	45	59

of the treated plots were not significantly different from those of the untreated ones. We conclude therefore that the seed dressings used are useless for controlling *S. lineatus.*

In a further experiment at Rothamsted, relatively heavy doses of demeton, aldrin and γ-BHC were applied as dusts on the seed drill, rates of active ingredient per 20-foot row being 2 g. for demeton, and 2 g. and 0·02 per cent g. for aldrin and γ-BHC. Plant counts showed that these treatments did not reduce the plant stand. Adult weevil damage was assessed by counting feeding notches on the youngest fully-formed leaves 6 and 8 weeks after sowing, and the results are shown in Table 5.

TABLE 5

Estimate of damage by weevils. Counts of notches on the youngest fully opened leaves

Insecticide	Rate of active ingredient per 20 row feet	Number of notches per pair of leaflets (average) of three replicates 6 weeks after sowing	8 weeks after sowing
Demeton	2 g.	3	1
Aldrin	2 g.	14	5
	0·2 g.	18	7
BHC	2 g.	15	8
	0·2 g.	21	9
Control		18	10
Control		19	9

It can be seen that demeton greatly reduced the adult feeding damage while the high aldrin and γ-BHC treatments had a slight effect. Larval attack was slight, and we had not the facilities to deal with large samples needed to show differences between treatments. However, it was apparent that no treatment had protected the roots against larval attack. In view of the high doses of insecticide which were used, it seems that soil insecticides are unlikely to control larvae of *Sitona lineatus*, although a systemic insecticide may be useful in the control of adults.

Control of wireworms

The experiment started in 1951, in collaboration with the Entomology Department, was continued by F. Raw and C. Potter.

The treatments applied in autumn 1951 were: none (0); BHC seed dressing 2 oz. of 20 per cent γ-isomer per bushel (S); 3·5 per cent BHC dust (0·42–0·45 per cent γ-isomer) combine drilled with seed at 56 lb./acre (G); 1·78 per cent aldrin dust combine drilled with seed at 200 lb./acre (A); 5 per cent chlordane dust combine drilled with the seed at 100 lb./acre (C); 5 per cent DDT dust combine drilled at 150 lb./acre (D).

The land has been kept under continuous wheat, and no further insecticide treatments have been made.

The yields of wheat in autumn 1954 were as follows:

TABLE 6

	0	S	G	A	C	D	Mean
	Grain (at 85% dry matter): cwt./acre						
Mean (± 1·03) ..	27·2[1]	29·4	32·9	31·0	29·7	29·2	29·2
Increase (± 1·19) ..		2·2	5·7	3·8	2·5	2·0	—

[1] ± 0·60. Mean dry matter % as harvested: 74·9.

These figures show that there was a significantly higher yield on plots previously treated with BHC (G), aldrin (A) and chlordane (C) combine drilled, compared with the control. There was no significant difference between the yields of the control and those from plots that had been treated with DDT (D) or had been sown with seed treated with BHC (S). Owing to the low general level of infestation, the experiment has now been discontinued, and the work is being prepared for publication.

ENTOMOLOGY DEPARTMENT

C. B. Williams

Staff

G. W. Heath, B. Johnson and Miss S. El-Ziady left during the year, and J. E. V. Davis (A.R.C. scholar) and P. F. Entwistle (Colonial Office scholar) joined the department.

Miss El-Ziady obtained her degree of Ph.D. of London University for a thesis entitled " Field studies in the flight activity of insects in relation to the physical environment ".

C. B. Williams visited the West African Cocoa Research Institute by the invitation of the Colonial Office in April 1953 (omitted from last Report), and again in May and June 1954, to advise on insect pests of cocoa, and particularly the mealy bug transmission of virus disease, and damage by Capsidae. He also visited the Netherlands in March 1954 by invitation of the Students Organization of the Dutch Universities, to give four lectures in different universities.

P. W. Murphy went to Austria in June 1954 to work in the laboratory of Dr. Kühnelt in Vienna for about a year.

At the end of the year under review F. Raw was seconded to the West African Cocoa Research Institute in the Gold Coast for a period of 2 years to study insect pests of cocoa.

Effect of Weather Conditions on Insects

(C. B. Williams, R. A. French and S. El-Ziady)

No continuous light-trapping was carried out during the year, but suction traps at 5 feet and at 30 feet were working for 2 hours each day, and each night from dusk till midnight. This work was incorporated in a Ph.D. thesis by Miss El-Ziady, and parts of it are now being prepared for publication.

Insect Migration

(C. B. Williams and R. A. French)

The observations in the Pyrenees, mentioned in the last Report, overlapped into the period of this Report, and during the year a paper has been prepared giving the main results of our expedition. Information on migrant insects continues to be sent in, both from the British Isles and from abroad. R. A. French is preparing a thesis on the migration of the Sphingidae in Western Europe.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes and G. W. Heath)

The twenty-eighth successive annual sampling of the wheat on Broadbalk showed that the percentage grain infestation by the wheat blossom midges was 4·7 in 1954, compared with 11·1 in 1953. Some preliminary experiments were made to test the effect of the freezing and the flooding in the normal soil sampling technique on the

subsequent emergence of the gall midges. Emergence of *C. tritici* and *S. mosellana* took place both after freezing and flooding during the winter and as late as May, but the Saddle gall midge (*H. equestris*), while able to withstand both freezing and flooding in the winter, did not emerge after freezing in May, although it survived flooding in this month.

The study of the biology of *Mayetiola* species attacking the lower part of the stems of cereals and grasses has continued. A stock of the Hessian fly (*M. destructor*) has been maintained on wheat and on couch grass. In experiments this midge intermated with individuals bred on barley, rye and couch grass. Inter-breeding was also obtained. These midges were originally collected on the various host plants on Rothamsted Farm at Harpenden. The host plants of these midges were shown to be interchangeable, and probably only one species is involved. An attempt to estimate the amount of infestation by the Hessian fly in the field was made. The study of a related species, *Mayetiola dactylidis*, from cocksfoot, which differs in life-history and habits, is being continued.

In experiments attempting to measure depression in seed yield of foxtail grass (*Alopecurus pratensis*) as a result of gall midge attack, no differences could be attributed to this group of insects. The experiments involved growing individual plants of a single clone, some of which were infested by gall midges, whilst others were kept free. Unfortunately differences in seed yield due to physiological blindness, thrips and other causes masked any loss due to midge attack.

The investigation into the biology of the lucerne leaf midge (*Jaapiella medicaginis*) was continued. Preliminary attempts to establish the host plant range, using black medick (*Medicago lupulina*), white clover (*Trifolium repens*) and red clover (*T. pratense*), were unsuccessful. Experiments were carried out to assess cocoon populations in the soil. It was found that whereas emergence of the midge was obtained from March and April soil samples that had been kept frozen, but not flooded, the numbers so obtained were considerably lower than from similar samples from which the cocoons were washed without undergoing cold storage.

A paper (134) on the importance of gall midges in the production of the small grains, especially sorghum, as well as a memorandum giving the available published and unpublished information on the gall midges of the sorghums, the panicum millets and rice (135), was prepared for the 6th Conference of Commonwealth Entomologists.

Since writing up the account of an investigation into the gall midges living in chrysanthemum flowers (129), it has been shown that *Contarinia chrysanthemi* can breed on the Daisy (*Bellis perennis*).

A study has been started on the gall midges living in white clover flowers (132). A *Dasyneura* species, injurious to seed production, was found to be widespread in England and Wales. Three other species were also discovered breeding in the flowers. Preliminary experiments indicate that this *Dasyneura* from white clover will intermate with a *Dasyneura* whose larvae feed on the developing seeds of red clover and will breed on red clover.

New gall midges whose larvae live respectively as predators of the eggs of *Pulvinaria* in Indonesia, as internal parasites of aphids

in Trinidad and in the blossom of privet (*Ligustrum*) in Britain have been described (137, 131, 133).

The object of this section has been to build up an international collection of gall midges and a library, while carrying out long- and short-term biological studies particularly on fluctuations and host-plant range, as well as providing facilities for training other workers and serving as a centre of information (130).

Aphid Problems

(C. G. Johnson, L. R. Taylor, Elsa Haine and B. Johnson)

Suction traps

In order to estimate insect densities two parameters must be known: the volume of air sampled and the proportion of insects in that air which are caught. With suction traps, the volume of air sampled varies with voltage, frequency and wind-speed; therefore the climate of the trapping site and the length of the cable cause fluctuation in air delivery. This difficulty is acute when sampling high in the air on a barrage balloon; and when different sized traps are used each must be accurately standardized for air flow. This has now been done by L. R. Taylor for six types of trap and the limits of error under all likely conditions assessed; for this work Taylor devised a new type of manometer.

The second problem—the proportion of insects in an air mass which elude the trap should, *a priori*, vary with the mass and flight speed of the insect and with the wind-speed; this is being investigated.

High-altitude dispersal

The work at Cardington continues, but much time has been spent dealing with 6 years' work and in analysing the results of other authors. Past workers failed to distinguish two processes in aerial dispersal: the distributive effect of meteorological forces on airborne insects and the effects of meteorological factors on the biological processes causing changes in numbers flying. When insects were trapped at various high altitudes, the catches at each height were often correlated with the meteorological factors at each height. It is, however, more convenient to combine the catches at all heights into a single parameter—the density-height gradient: this is independent of gross numbers flying and is an expression of the degree of mixing. The gradient varies with time of day and with season; it is steeper (i.e. a greater proportion of aphids are in lower levels of the atmosphere) with low lapse rates; and this type of distribution is often characteristic of the autumn. High lapse rates and shallow gradients (i.e., more mixing) are often characteristic of spring and summer. The gradient can be integrated to give an estimate of total insects in the air: and the total number of aphids flying up to at least 1,000 feet often shows the double peak characteristic of density change near the crop.

Moulting, parturition and flight rhythms

We have shown that the number of *Aphis fabae* flying are strongly affected by the rhythm of moulting into the alatae. In

the field this rhythm is characterized by a peak of moulting in the morning, followed by a decline, with a later resurgence in the afternoon and evening, and it is to some extent correlated with temperature. Dr. E. Haine has now shown that this rhythm persists for many weeks, even when the insects are kept under constant illumination at constant temperature. A similar rhythm exists for parturition. Thus the rhythm at birth continues in moulting, flight, and eventually often in the rise and fall of total numbers in the air up to 1,000 feet and probably more. In connection with this work L. R. Taylor has investigated the flight rhythms of *Drosophila*.

Aphid flight

Dr. E. Haine has also shown that some tree aphids (e.g., *Drepanosiphon platanoides*, *Phyllaphis fagi* and *Euceraphis punctipennis*) are able to fly when they are a considerable age (30 days at least with *Drepanosiphon*) : they differ, therefore, from *A. fabae, M. persicae* and others whose wing muscles autolyse after a few days of activity.

B. Johnson has been working on the behaviour of alate aphids. After the final moult young alatae enter into an excited state in which they are indifferent to their host plant, and require a short flight or other exercise before they will become responsive to it. The main factors influencing the acceptance or rejection of a host are the age and quality of the plant, and the experience of the aphid immediately before alighting, e.g., the length of flight it has undertaken. The physical environment is of less importance, although adverse conditions for flight may have an effect on the larviposition response in some species of aphids, as distinct from the physiological processes of embryo development and flight muscle histolysis, which are dependent on the aphid fully accepting a host plant.

A New Method of Sampling Insects in Herbage by Suction Pump

(C. G. Johnson, C. J. Banks and T. R. E. Southwood)

A new sampling method for insects on grassland, herbage, hedgerows, etc., has been developed in which a powerful suction pump removes the insects and deposits them in a detachable bag. It is particularly suitable for removing the free-living population in the deep interstices of matted vegetation; preliminary tests show that a high proportion of the total insects, and in some cases (e.g., capsids) a complete extraction, of a given area is possible in a very few minutes without removing plants, etc., to the laboratory.

The Natural Enemies of Aphids

(C. J. Banks)

Some of the conclusions from earlier studies on the movements and behaviour of ladybird larvae (Coccinellidae) have been given in the Report for 1953. The high mortality in the field of young larvae occurs, it seems, soon after they have dispersed from the egg shells. The studies were resumed during 1954, with special reference to the movements of unfed, newly-hatched larvae, whose small size called for the development of a technique for locating them on plants in the field.

Satisfactory results were obtained for well-grown larvae of the large species *Coccinella 7-punctata* by attaching labels containing radium sulphate to the insects. For the small, very active, first-stage larvae these labels were too large and other materials had to be found; experiments with ^{32}P, mixed with an adhesive applied to the thorax, were unsuccessful, but radioactive tantalum (^{182}Ta) was found to be a suitable material for attachment with glue or cellulose paint to the larvae. Labels, cut from a strip of the irradiated metal, measured approximately 0·05 mm. × 0·10 mm. × 0·23 mm. and on the average weighed 0·03 mg. Simple techniques were developed for cutting the labels and for holding the larvae still while labels were being attached. These labels could be detected at a distance of 1–1·5 feet, and were suitable for larvae of all sizes and, no doubt, could be used for other small crawling insects.

Injurious effects of this treatment of larvae were sought. No changes in the behaviour or in the growth of first-stage larvae carrying labels of unirradiated tantalum could be observed, but labels of an initial specific activity of 250 μc./mg. specific activity, while not so readily detected, proved satisfactory, for no adverse effects could be observed on the behaviour of the larvae or on the rate of growth of any immature stage of the insects.

The results of laboratory and field studies in which these techniques were used are being prepared for publication.

Heteroptera

(T. R. E. Southwood and P. F. Entwistle)

T. R. E. Southwood has continued his study of the ecology of various Heteroptera associated with field margins and hedgerows. During the winter, grass stems were examined and the number, conditions and species of Mirid eggs recorded; mortality factors recognized were parasitism by Mymarids and crushing when the grass stem twisted and contracted on drying. The numbers of parasites emerging per unit area of ground was estimated by means of emergence traps. During the summer, samples of the larvae and adults of Heteroptera were taken by sweeping and with the vacuum method of sampling (see above). Each species was found to have its own special habitat within the grassland, for example the larvae of *Capsus ater* L. occur only around the bases of the grass; whilst those of *Stenotus binotatus* Jak. are confined in the early instars to the flower heads of Cocksfoot grass (*Dactylis glomerata* L.), and later instars live on the heads of other grasses and wheat.

An estimation of the population of adult *Leptopterna dolabrata* L. by marking and recapture was carried out in July; from a preliminary analysis of the results it would appear that the expectation of life, after capture, was low, in the order of 5 days. By sweeping the wheat adjacent to the experimental area and from the catches of a suction trap running in the area, it was found that very little migration of *L. dolabrata* occurred during the experiment. A study of the bionomics of the two thistle lace bugs, *Tingis ampliata* H.-S. and *T. cardui* L., has been completed; in this Mr. G. G. E. Scudder has collaborated.

A survey has been made of the morphology of the salivary glands of terrestrial Heteroptera; this work and that on egg structure,

which is continuing, have contributed to a revision of the superfamily classification.

A taxonomic revision of the world species of the Mirid genera *Cyrtorhinus* Fieber and *Mecomma* Fieber, the first of which is important in biological control, is being carried out in collaboration with Dr. J. C. M. Carvalho of Brazil.

During July a short visit was made by T. R. E. Southwood to the Nature Conservancy's Merlewood Research Station to survey, with Dr. J. E. Satchell, the Heteroptera of natural woodlands in the Lake District.

In collaboration with Mr. D. Leston a study is being made of the range of variation of taxonomic characters of various Heteroptera, including *Blepharidopterus angulatus* Fallen, an important predator of the red spider mite.

P. F. Entwistle has commenced a comparative study on the oviposition sites, eggs and larvae of the various mirids occurring on oak; in connection with this work he is investigating the structure of the female genitalia of mirids.

Effects of Population Density on Insects

(D. B. Long)

The work on the effects of population density on larva of Lepidoptera has been continued, and a more detailed study of the processes involved in larval darkening and the faster rate of development is being made. The work has been extended to include Heteroptera, and aggregation has been observed to induce a faster rate of development in *Stollia fabricii* Kirk. The fact that the population density may produce similar effects in orders other than Lepidoptera or Orthoptera is supported by a recent observation in the literature on Coleoptera, which with a consideration of the small numbers that may be involved, will indicate the potentialities of these biological principles in the field.

Photo-colour response in lepidopterous larvae

The colour of the spots of the older larvae of the Emperor moth (*Saturnia pavonia* L.) are known to be variable, the spot colour of the individual larva generally being uniform. Apart from certain larvae in which they are black or white, the colour of the spots may range from pale yellow through orange to pink. Experiments showed that the colour which appeared during each of the last two instars could change from yellow to pink and that the extent of the change depended on the intensity and duration of the light to which the larvae were exposed. This photo-response was locally determined for each spot, and did not involve a central nervous reflex depending on light entering the ocelli.

Soil Section

Wireworm studies (F. Raw, R. M. Dobson, J. W. Stephenson and J. R. Lofty)

The studies of wireworm populations on the ley and arable rotations are now almost complete and will be concluded when the present first- and second-year plots have reached their third year.

The results of the Geescroft experiment on the chemical control of wireworms are now being prepared for publication in collaboration with the Insecticides Department.

Experiments to investigate the populations and movements of *Agriotes* adults were carried out in Geescroft and on Highfield pasture. The method used was that of marking and recapture, and the results are being considered together with those of the essentially similar experiment carried out last year.

Earthworm studies (F. Raw and R. M. Dobson, in collaboration with Soil Survey)

It has been suggested that soil organisms, especially earthworms, may play a considerable rôle during the rehabilitation of grassland which, due to the combined effects of acid soil, sheep grazing and neglect, has reverted to Nardetum. The organisms may help to break up the characteristic surface mat of rhizomes and to improve the physical structure of the soil. Experiments have been laid out on two hill farms in Lancashire in which, after a basic treatment of liming and surface cultivation has been applied to all plots, the effects of dung and balanced artificials at two levels of earthworm populations will be studied. Changes in the vegetation, the soil profile and the populations of earthworms and soil arthropods will be noted, and the productivity of the plots will be assessed by taking periodic grass cuts. Preliminary observations have indicated very low populations of earthworms on both sites.

Studies on Protura (F. Raw)

The results of the observations on the Protura of Park Grass have been prepared for publication. 1,425 Protura were extracted from ninety soil samples by flotation (each sample was 2 inches diameter and 9 inches deep). Eighty-five per cent of these were *Proturentomon minimum* Gisin and the remainder a species of *Eosentomon*, probably *E. armatum*. They were aggregated in such a way that the majority of individual sample counts fell within the range one-half to twice the geometric mean of the population. The degree of aggregation appeared to be independent of the population density. Their distribution was associated with conditions induced by liming, and both species were correlated with exchangeable calcium. *P. minimum* was also correlated with soil pH, and the abundance of *Avena* spp. and *Dactylis* spp.

Studies on millipedes (J. W. Stephenson)

Work on the biology of millipedes has continued. Cultures have been successfully maintained in the laboratory in order to investigate life-cycles, and last year's feeding experiments are being repeated so that differences between species can be more accurately assessed. Regular field collections and associated ecological studies have been made since spring.

Studies on Coleoptera (R. M. Dobson)

Limited field and laboratory observations on the bionomics of the cabbage stem flea beetle (*Psylliodes chrysocephala* L.) have been carried out. The results are now being prepared for publication. Some systematic work has been carried out on the species of *Carpo-*

philus (Nitidulidae) associated with stored produce. Three new species have been found amongst material submitted for identification.

Wheat Bulb Fly (*Leptohylemyia coarctata* Fall.)

(Barbara M. Stokes, D. B. Long and F. Raw)

Barbara Stokes reports that an investigation into the host plants of wheat bulb fly was begun. Flies were reared in experiments from newly hatched larvae on seven different common British grasses, from four plants related to wheat, and from wheat and rye. Larvae were also found feeding in experiments in three further plant species and typical damage occurred in six others, all in the Gramineae.

Larvae were able to move in the soil at least 7 inches (a usual drill width).

Breeding stocks of flies were maintained successfully in captivity in order to continue the host-plant experiments.

Larval studies (D. B. Long)

A survey was made in early spring of 1954 of larval infestation on the Rothamsted and Woburn soils in which samples were obtained from seventy plots of winter wheat involving different manurial treatments, and ten different previous crops.

From the samples taken, the sandy loam of Woburn did not appear to be so heavily infested as the clay loam at Rothamsted, though in both cases the heaviest infestations followed a summer fallow. At Rothamsted the highest infestation occurred in wheat of the four-course experiment on Hoosfield, where 87 per cent of the plants contained larvae, although 98 per cent of them had been attacked at the time of sampling, involving the destruction of 75 per cent of the existing shoots. Other plots carrying high infestations were Broadbalk, the wheat in the six-course experiment on Long Hoos 4, and the Wheat and Fallow experiment in decreasing order of intensity. Some infestation occurred in wheat following potatoes, whilst relatively low attacks followed previous crops of barley, wheat, lucerne, ley and cut grass.

Adult studies

Observations were made on the relative numbers of flies occurring on wheat plots. Male flies were first caught on 21 June and females a day later. The largest numbers of flies were always obtained in the sweeps made at 6.30 a.m. The minimum flight temperature was found to be 12° C. The results showed that as the daily temperature rose above this value the flies dispersed from the wheat and generally did not settle again in any number on the crop until dusk. From the recaptures from 2,000 flies which had previously been marked and released, and from the uneven distribution of the existing population, the flies appeared to stay in the vicinity of the plots from which they emerged. They also tended to aggregate on the lee side of the crop. Generally at low wind speeds the flies were found to be on the top of the wheat, but with higher speeds, i.e., 15 m.p.h., they were found close to the ground.

Oviposition rhythm

Although looked for, oviposition was not observed in the field. Observations on caged females under laboratory conditions showed a distinct diurnal rhythm. Egg laying began in the afternoon and rapidly rose to a maximum during the 2 hours before dark. Few or no eggs were laid during the night or morning. The rhythm was not dependent on light, but was influenced by it.

Eggs

Eggs are known to develop for a period of up to 2 weeks before entering diapause, and a study was made of the water relations during this period. The eggs were found to lose water rapidly unless kept at 100 per cent relative humidity. Eggs kept at 77 per cent relative humidity lost one-fifth of their total water in 13 days, resulting in 50 per cent mortality. The rate of water loss was found to depend on both physical and physiological factors. Water once lost could not be recovered when returned to saturated conditions.

F. Raw reports as follows :

Preliminary observations on Broadbalk suggested that the intensity of wheat bulb fly attack might be affected by the quantity of organic residues in the soil influencing oviposition and by the density of wheat shoots available to the larvae at hatching time. A factorial experiment laid out on Pennell's Piece to investigate the effect of various soil conditions on oviposition showed that manuring had no effect on the number of eggs laid, but that a rough tilth was preferred for oviposition to a smooth one. Cultivation of the soil during the oviposition period appeared to create conditions favourable to oviposition, but it could not be ascertained whether this was due to an increase in the number of possible oviposition sites or to some property of freshly cultivated soil which was attractive to the insects.

By covering parts of selected plots on Broadbalk fallow with mosquito netting during the oviposition period, small areas free from wheat bulb fly eggs were obtained. These will be harvested separately so that the effect of the infestation on the yield of the crop can be estimated.

Forest Soil Investigations

(P. W. Murphy)

Preliminary investigations have commenced to consider in greater detail the litter fauna of different tree species, singly and in mixture, together with their associated " humus " formations. It is intended to consider especially the food habits of individual species of Acarina and Collembola occurring in the litter. A problem encountered in the search for suitable sites for this work is the absence of information concerning the soil properties of what are otherwise suitable locations. However, some plantations in Thetford Chase, Norfolk, appear promising, and the investigations of Dr. J. D. Ovington of the Nature Conservancy provide valuable information on the chemical and physical attributes of the soils in this area. A preliminary survey has been made of the meiofauna of single-species plots at

Olleys Farm, Thetford Chase, one of the plantations sampled by Ovington.

With the intention of investigating the effect of environmental factors such as precipitation, a search has been made for other areas with thin iron-pan soils similar to that encountered in parts of the Allerston Forest. A site near Bolton, Lancashire, has been sampled to ascertain the effect of the much higher rainfall prevailing in this area. Preliminary results would suggest that more attention should be paid to the relative proportions of the various layers of the raw-humus horizon. The Bolton samples have a well-developed F layer, and this may partly account for the greater biomass and faunistically richer population inhabiting this site. E. Crompton and other members of the Soil Survey team at present working in Lancashire have given generous assistance and advice.

In June P. W. Murphy received a special grant from the Forestry Commission to enable him to spend a year with Professor Kühnelt at the Zoological Institute of the University of Vienna. Professor Kühnelt is a well-known authority in the field of soil animal biology, and he and his students have carried out a considerable amount of research on the fauna of forest soils. This work includes surveys field observations and laboratory studies of the food habits and biology of individual species.

Preliminary Observation on the Effect of Weed-killer on Insect Populations

Co-operation with the Nature Conservancy and the Agricultural Research Council

(C. G. Johnson, R. M. Dobson, T. R. E. Southwood, J. W. Stephenson and L. R. Taylor)

The widespread use of weed-killers may have undesirable effects on some animals and on the balance of nature; because of the lack of information, experiments were planned by the Agricultural Research Council and The Nature Conservancy primarily to assess the effect on bird life of DNOC sprayed on winter-wheat. We were asked to observe the effects on the arthropod fauna.

Two fields, ½ mile apart at Ardington, Berkshire, were among those selected; but, though superficially similar, they had different histories, weeds and insect populations. One field was sprayed, one left untreated. For some days before and for some weeks after spraying, sampling was carried out of the air above the fields by suction traps, of the herbage by sweeping and of the soil. Control soil samples were also taken from protected parts of the sprayed field.

The course of population change in both fields was similar, though the control field had a naturally higher population. The population on *both* fields declined after the date of spraying, and the effects of the DNOC were therefore difficult to detect. On the sprayed field, however, the decline set in one day earlier than on the control, and samples by sweeping suggest that the spray may have been responsible for this (Table I). No effect attributable to the spraying was noticed beyond this one day, except in the soil.

In 6-inch-deep soil samples no effects were detected on total

population, though surface-living Collembola and Thysanoptera were fewer on sprayed land. In 2-inch-deep samples Collembola were fewer on the sprayed field than on the controls for at least 3 weeks after spraying, though this difference was not statistically significant.

TABLE 1

Daily suction trap catches

May	7	8	9	10 *	11	12	13	14	15
Sprayed ..	532	631	779	4,836	4,483	2,481	3,326	694	1,080
Unsprayed	3,206	4,869	2,390	7,784	16,371	11,000	13,000	3,735	216

* Date of spraying.

Of all insects caught by trapping, only 14 per cent were definitely non-residents : this is probably a gross underestimate. The probable effect of spraying on resident populations was indicated by sweeping sprayed and unsprayed portions of the same field on the day after spraying (Table 2). A detailed analysis of groups and species showed that though most insects diminished, Frit flies and aphids increased after spraying.

TABLE 2

	Sprayed	Unsprayed
Diptera	38	129
Auchenorrhyncha	8	32
Symphyta	2	6
Collembola (Sminthurus) ..	7	49
Lepidoptera (larvae)	3	11
Heteroptera	2	18

A detailed report has been circulated, but this complex problem needs experiments of longer duration, with more replication and more controls, if increases and decreases associated with spraying are to be distinguished from natural population fluctuations.

BEE DEPARTMENT

C. G. Butler

General

A number of lectures have been given by members of the Department to Scientific Societies, Beekeepers' Associations, etc., and assistance has been given at several week-end courses for beekeepers and others. Members of the Department have also continued to serve on various committees, including the Ministry's Bee Disease Advisory Committee and the Honey Marketing Standards Advisory Committee.

L. Bailey and C. G. Butler attended the XV International Beekeeping Congress in Copenhagen and read papers; they afterwards took part in an International Conference of Bee Research Workers at the Danish Bee Research Station.

L. Bailey and J. B. Free have both been awarded the Ph.D. degree of London University, and J. B. Free, who has held a special grant from the Agricultural Research Council for the past three years, has now been appointed a Scientific Officer in the Department.

Elizabeth Tyndale-Biscoe and Nancy Free have resigned in order to devote their time to domestic duties.

Bee Behaviour

Foraging behaviour

The effect of the scent of a crop in initiating the foraging activities of bees who have already learned to associate this particular scent with food has been demonstrated by C. R. Ribbands. He trained equal numbers of bees from a single colony to seek food in the afternoon only from each of two dishes of sugar syrup containing different scents and placed 50 yards apart. Subsequently both dishes of food were made available to the bees in the morning, and at the same time a small quantity of one or other of the scents associated with the dishes was placed in their hive. It was found that the addition to the hive atmosphere of the scent to which she had been trained doubled the chance that a bee would visit her feeding-place outside the usual feeding-time. It appears, therefore, that the foraging activities of bees may be initiated by the appearance in the hive atmosphere of a scent which they have learned to associate with food even in the absence of any dancing.

This observation may be expected to have a bearing on the elucidation of the problems involved when attempts are made to direct bees to particular crops for pollination purposes.

The influence of the psychological condition of a forager on the recruitment by her of further members of her colony to exploit a particular crop has also been investigated by C. R. Ribbands. He trained equal numbers of individually marked bees belonging to a single colony to collect syrup from each of three dishes placed in different directions from their hive. Dilute sugar syrup was supplied in one dish and concentrated syrup in another, whilst the third dish

was first supplied with dilute, and later with concentrated, syrup. It was found that twice as many recruits always appeared at the dish in which the syrup concentration was increased as appeared at the dish in which a supply of concentrated syrup was constantly maintained.

It appears, therefore, that an improvement in the concentration of the nectar in the flowers of a crop is likely to cause the bees who are foraging on this crop to dance more and to disseminate more bee scent, and thus to attract more recruits to this crop, than bees on another crop in the flowers of which the nectar concentration remains constantly at a high level. This may account for some of the hitherto unexplained results of competition between flowering crops for the attention of pollinating bees.

Swarming

J. Simpson has continued to study the nature of the swarming impulse in honeybee colonies. In experiments in which colonies whose bees were making preparations to swarm were paired with colonies whose bees appeared to be making no attempts to do so, the queens of the two colonies of each pair were interchanged. Under these circumstances it was found that in some cases swarm preparations were made by the bees in either, or both, of the colonies of a pair. It therefore appears that the change which precedes swarm preparations is not confined either to the queen or to the workers of a colony.

This conclusion is reinforced by data collected by C. G. Butler, following upon an observation by J. Simpson that the workers of a colony will sometimes attempt to rear a new queen for themselves, even though their old one is still present, but after she has remained tethered amongst them for some time. Thus, for example, it has been found that if a mated queen is tethered on a comb in her hive in such a way that, whilst her movements are greatly restricted and she does not lay eggs in cells, the workers of her colony have ready access to her body at all times, her bees look after her and, for at least a week, make no attempt to rear a new queen for themselves. Indeed, some colonies, although continuously provided with young female larvae with which to do so, made no attempts to rear new queens, even when their own queens remained tethered for several consecutive weeks. However, the bees of most colonies started to do so after their queens had been tethered continuously for 10 or 12 days and, on being released, their queens in three cases out of fifty actually laid eggs in queen-cell cups, thus co-operating actively in the swarming preparations that their colonies were making. Interchange of such "swarming" queens with "non-swarming" ones yielded results similar to those obtained by J. Simpson and mentioned above. Usually, however, within 2 or 3 days of the release of a tethered queen in whose colony queen cells had been commenced, all the queen cells were destroyed by the bees and her colony returned to a non-swarming condition.

The organization of social life

By making use of radioactive ^{14}C sugar C. R. Ribbands has been able to extend his investigations to determine the extent to which the bees of a colony share the sugary liquids which are collected by

the various members of their community. The data obtained in his most recent experiment indicate that a load of radioactive syrup which was collected by a single bee was ultimately shared amongst nearly all the 20,000 members of her colony. This result strongly supports the hypothesis that the individual odour which each colony of honeybees possesses, and which is common to all the members of the colony and differs from those of other colonies, is derived, to a considerable extent if not entirely, from the food which the members of the colony have been sharing amongst themselves. Thus the bees of a colony are enabled to recognize, by means of their body odours, members of their own colony and to distinguish them from intruders from other colonies.

This last and most important conclusion has been agreed by those who have worked on this subject most recently (Kalmus, H. & Ribbands, C. R. (1952). *Proc. roy. Soc.* B., **140**, 50; Butler, C. G. & Free, J. B. (1952). *Behaviour*, **4**, 262; Ribbands, C. R. (176) & Free, J. B. (174)). However, there is still some disagreement between these authors with regard to the part which the behaviour of an intruder, particularly that of a would-be robber bee, plays in determining the kind of treatment to which she is subjected by any guard bees who intercept her.

C. G. Butler has continued his work to determine the nature and function of the substance (" queen substance ") which the household bees of a colony seek by licking the body of their queen. Some of his earlier results have been published (173). There is good reason to suppose that inhibition of ovary development in worker bees, as well as inhibition of queen-cell production, is dependent upon the circulation amongst the members of a honeybee colony of an adequate quantity of " queen substance ". That this is indeed the case has recently been demonstrated by adding to the protein-rich diet on which a group of queenless bees were being kept, the honey-stomach contents of other worker bees who had just been licking the bodies of their queens. Ovary development in these experimental bees was significantly less than that in a control group, fed on the same diet except that the honey-stomach contents added were obtained from bees who had not been near a queen for several days. It has also been found that whereas a mated queen normally produces sufficient " queen substance " to inhibit queen-cell toleration and production by the workers of her colony, a virgin queen does not always do so. It is hoped to publish further results of these investigations shortly.

General Research

Nutrition of honeybee larvae

In the past it has been supposed that the addition of pollen to the diet of a female honeybee larva is essential in order to provide the larva's protein requirements. Further, it has even been supposed that, since those larvae which are destined to become queens usually receive very little pollen, the addition or otherwise of pollen to the diet of a female larva may help to determine whether a worker bee or a queen is produced. However, by means of estimates, based upon haemocytometer counts of the number of shells of pollen grains in the guts of mature larvae, J. Simpson has shown that

different worker larvae receive a variable amount of pollen in their diet in summer, and sometimes none at all in winter. It is, indeed, probable that, even in summer, less than a tenth of the protein requirements of a larva are supplied in the form of pollen.

Division of labour in Bumblebee colonies

J. B. Free has continued to work on the biology and behaviour of bumblebees. In studies on the division of labour amongst the workers of a colony he has confirmed that the larger individuals go foraging more often than their smaller sisters, and that those of the smaller members of the colony who do go foraging do so less regularly than the larger ones. Thus the division of labour into its two main sections—household duties and foraging—appears to be largely dependent upon the body sizes of the bees concerned. In fact, about two-thirds of the workers of any colony are either constantly concerned with foraging or with household duties, but the remaining third carry out both these duties at different times in their lives. However, it was found that, as in the case of honeybees, individual workers will adapt their behaviour and forsake one occupation in favour of another to meet the current requirements of their colonies.

The type of food (nectar and pollen) which foraging bumblebees collect is also determined to some extent by the needs of their colonies. Thus both the number of larvae present and the nature of the food reserves in their nests have a marked bearing on the type of food collected at any given time.

Behaviour of egg-laying workers in Bumblebee colonies

If a colony of bumblebees loses its queen, the ovaries of many of its workers soon develop, provided that they have adequate nourishment, and unfertilized, male-producing eggs are laid. J. B. Free has studied the behaviour of workers who, having lost their queen, have commenced to lay eggs. He found that in each colony one of the workers became " dominant " in her behaviour. Such a dominant individual spends most of her time incubating a new clump of eggs, which she herself has probably laid, and actually drives other members of her colony away from them.

In some queenless colonies a hierarchical system developed, similar to the " pecking order " in flocks of birds. In these cases a particular laying worker was dominant and attacked all the other members of her colony, and in many cases a second worker who attacked all bees except the dominant individual was also present. Indeed, in a few cases a third individual was present who attacked all the members of her colony except the two individuals who were higher in the hierarchy than herself. It was found that the behaviour of any individual bee and, consequently, her position in a hierarchy, is correlated with the state of development of her ovaries. The most dominant individuals possessed the most highly developed ovaries.

Biometrical investigations

Elizabeth Carlisle has continued her studies of the characteristics of ten supposedly pure races of *Apis mellifera*, specimens of which the Rev. Brother Adam very kindly collected for the Department from countries in Western Europe, North Africa and the Eastern

Mediterranean. The characters measured were those which have previously been found to show the greatest racial variation—length and width of fore-wing, length of tongue and hind-leg, number of hooks on the leading edge of the hind-wing, and the cubital index (ratio of lengths of two veins in the fore-wing). The specimens were also classified by colour, the number of broad or narrow light-coloured abdominal stripes and the presence or absence of a light-coloured scutellum being the characteristics studied.

From the data obtained it appears that a fairly distinct trend of racial variations extends from North-west Europe to the eastern Mediterranean, but few clear-cut differences are apparent between bees in adjacent regions. The samples of German, French and Swiss bees examined were very similar in most respects, and together appear to form a group, the members of which differ from the bees of Italy in cubital index, tongue length and hind-leg length, and from the so-called Carniolan race in cubital index and tongue length. The bees from Greece and Crete were found to be similar in all the characters measured except for the cubital index, which in the Cretan bee is very near the French index. The bees of the Syrian and Cyprian races were found to differ in fore-wing and tongue lengths only; and bees of the Tellian race from North Africa and of the Sicula race from Sicily only differed from one another in fore-wing length.

It is hoped that a detailed account of this work will be published shortly.

Queen introduction

With the help of a number of beekeepers, including members of the Bee Research Association, C. G. Butler has continued to study the problems involved when a queen reared in one colony is introduced to the bees of another colony whose queen has been removed. During 1953, 230 mated queens of different ages, including nearly 100 that had been through the post or caged in mailing cages for periods as long as 5 days, were introduced to colonies, by means of a very simple cage, directly the old queens had been removed. Only one queen was lost. During 1954 several hundred queens have again been introduced successfully and with a minimum of trouble, but several queens have been lost.

The reason or reasons for these losses is still uncertain, but experimental evidence has been obtained which strongly supports the assumption that some of them were due to the bad temper of the bees of the recipient colonies.

It is hoped to continue these investigations during 1955, when it is proposed to experiment with a slightly modified cage which, while still retaining those features which have been shown to be desirable in the earlier experimental cage, will also ensure that the queen cannot be released by the bees of the recipient colony before the end of a predetermined period of time. In this way it is hoped that all difficulties will finally be overcome.

Bee Diseases

Nosema disease

L. Bailey has now demonstrated that the transference of all the adult members of a colony on to clean combs during the early

summer is an effective means of eliminating infection with *Nosema apis*. Furthermore, the brood in the old combs can be allowed to emerge and join the colony, the bees of which can also recover stores of food from these old combs, before they are removed for sterilization. Such sterilization can be carried out effectively with the fumes of glacial acetic acid or, if no honey or pollen remain in them, with formaldehyde. A full account of this work has been published.

Acarine disease

L. Bailey and Elizabeth Carlisle have carried out trials with a number of acaricides applied as a smoke to bees infected with *Acarapis woodi*. "Ovotran" (*p*-chlorophenyl, *p*-chlorobenzene sulphonate) was particularly effective. The number of larval mites and eggs in infected bees treated showed a highly significant reduction a few days after treatment. Indeed, it was found that all life stages of *A. woodi* were destroyed.

European Foul Brood

L. Bailey has attempted several times to infect small, healthy, honeybee colonies with bacteria which were considered to be the possible causal organisms of European Foul Brood. On several occasions Professor L. P. Garrod, who has kindly been co-operating by attempting to cultivate the suspected organism (*Bacillus pluton*), has obtained a weak growth of a very similar organism (a strictly anaerobic, encapsulated *Diplococcus*) from diseased larvae which has been tested in this way. On all but one occasion no infection was found, but in one trial a large, apparently growing, collection of Gram +ve organisms closely resembling *B. pluton* was found in one larva.

F. A. Skinner (Microbiology) has also attempted to culture the causative organism. He isolated several Gram +ve cocci, all of which were facultative anaerobes. These were tested in hand-reared honeybee larvae, but none grew. On the other hand, a good growth of *B. pluton* was obtained in control larvae infected with "scale" material.

A convenient, but still not entirely satisfactory, method of hand-rearing larvae was devised late in the season. Day-old larvae were grafted into empty cells of wax or glass and fed with food taken from larvae in hives. The experimental larvae were kept in screw-topped jars containing about 20 ml. of 50 per cent KOH. Such larvae grew well to full size, but never pupated.

So far completely satisfactory methods of testing artificially-cultivated organisms for pathogenicity have not been developed. Nevertheless, much work upon the epidemiology of the disease can be done without cultivating the responsible organism, and L. Bailey has commenced working on these problems.

STATISTICS DEPARTMENT

F. YATES

The new temporary building adjoining Rivers Lodge was completed in March and has provided much-needed additional accommodation. The Hollerith equipment is now housed in this building, and this has considerably improved its efficiency of utilization. The lecture and conference room included in this building has also proved very useful, both to the department and to the Station generally.

Three members of the scientific staff left during 1954. P. M. Grundy has taken a post with the National Foundation for Educational Research, N. E. G. Gilbert has gone to work under Sir Ronald Fisher on an Agricultural Research Council grant and P. R. D. Avis has taken a post with the Air Ministry.

New appointments were : S. Lipton, from Liverpool University, A. J. Whitwell, from the R.A.F. Flying Training Command Research Branch, Sheila Cohen from Electrical and Musical Industries Ltd. and D. J. Knight, from the War Department, R.E.M.E., Leicester, as technician for the electronic computer. R. W. Sharp is spending 2 years in the Department working for a Ph.D. on a Ministry of Agriculture Post-Graduate Scholarship.

G. E. Hodnett spent 4 weeks in the West Indies visiting agricultural and statistical departments in Jamaica, Trinidad and British Guiana.

Twelve temporary workers were accommodated in the department during the year, three from Great Britain, one from Australia, seven from the Colonies and one from Belgium.

THE ELECTRONIC COMPUTER

The outstanding event of the year has been the installation of the N.R.D.C.—Elliott 401 electronic computer in the department. The machine, which is the property of the National Research Development Corporation, is being run on a joint basis, half of the time being at the disposal of Rothamsted and half at the disposal of the National Research Development Corporation. The machine was installed at the beginning of April, and was in running order by the middle of May. Since that time it has suffered no major breakdown, and has generally proved itself reasonably reliable. D. H. Rees, who with the initial assistance of Mr. H. G. Carpenter of the National Research Development Corporation has been responsible for keeping the machine in working order, deserves great credit for this.

It is often thought that the main feature of electronic machines is their speed. This is only part of the story. Equally important is their ability to perform long and complicated trains of operations without the intervention of the human operator; indeed, without this feature their speed would be of little value. It is thus possible to perform the *whole* of a complicated statistical analysis on the machine " untouched by human hand ". A good example is the analysis of randomized block experiments mentioned below. The

results are presented in the form of treatment number, yield and residual of each plot, arranged in the layout of the actual experiment (these can be suppressed if not required), the degrees of freedom and mean squares of the analysis of variance in the usual form, the standard error per cent per plot, the treatment means and their standard error, and the general mean. A conversion factor can be applied if required, and routines are being written to calculate quantities such as the plot yields of sugar from yields of dirty roots, sample weights of clean and dirty roots and sugar percentages. The whole operation consumes about 3 minutes of machine time for an experiment of about forty plots, of which 2 minutes is occupied by getting the data into the machine and punching out the results for printing on the teleprinter.

The programming of a series of operations of this type, i.e., the writing of the necessary instructions (orders) and testing their accuracy is, as might be expected, a time-consuming, if fascinating, task—the randomized block routine contains some 300 orders, most of them obeyed many times over in the course of the analysis of a single experiment—but once the programme has been constructed and tested it is available for use whenever required. All that is necessary is to feed the appropriate routine tape into the machine, an operation which, with the fast-input technique now being developed, will, for the randomized blocks routine, take between 1 and 2 minutes. The machine is then set up to analyse any required number of experiments. This may be contrasted with the time and skill required to plug a Hollerith plug board for even quite simple operations.

For those who are interested in technicalities it may be mentioned that the 401 is a serial computer with a word length of 32 binary digits and a word time of 100 μs. The main store is a magnetic disc of 23 tracks, each holding 128 words (orders or numbers); 7 of the tracks are always immediately available to the computer, but only 1 of the remaining 16 is accessible at any given time, switching between these tracks being by means of high-speed relays. There are 5 single-word immediate-access registers; one is the accumulator, which can be coupled with a second register for double-length working; the other 3 registers can each be used to modify orders (B modification) as well as for temporary storage of numbers. Input is by five-hole punched tape, and output by either electrical typewriter or teleprinter-punch. The machine has a two-address code to allow for optimum programming. Operations performed directly by the machine include addition, subtraction, multiplication with and without round off, collation, non-equivalence, discriminations on zero or negative values, and left and right shifting of single- or double-length numbers. Addition and subtraction take one word time (100 μs) to carry out, a shift of n places takes n word times and multiplication 31 word times (3·1 msec.).

Before it came to Rothamsted the machine was in the Mathematical Laboratory at Cambridge for 6 months, but the first magnetic disc proved unsatisfactory, and a new one was fitted only a short time before it left Cambridge. Consequently the machine came to us with practically no sub-routines, and a considerable amount of work has consequently been required to build up an adequate library for our purposes.

The machine has, however, already done some useful work. A routine for analysing randomized block experiments (M. J. R. Healy) is in operation, and has been used to obtain results for several large series of experiments. It is expected that by the end of the present winter about 300 separate analyses will have been carried out for the National Institute of Agricultural Botany and about 100 for the National Agricultural Advisory Service, as well as miscellaneous analyses for Rothamsted and other research centres. Work on the routines for the analysis of commonly occurring designs of more complicated types—factorial experiments, Latin squares, split-plot designs, etc.—is under way; it is expected that a number of these routines will shortly be in working order.

A number of routines for multivariate work have already been completed, and others are being prepared. A problem of discriminating between the teeth of men and of great apes by means of measurements is being investigated, using a large body of data collected by Dr. E. H. Ashton of the Department of Anatomy, Birmingham University (M. J. R. Healy). It is hoped that this investigation will throw some light on the nature of the australopithecine fossils.

A thorough investigation of the efficiency of the "combination of probabilities" test of significance has also been completed (F. Yates and Averil M. Munns). This required a large volume of computing on the machine, and has given illuminating and conclusive results. The problem is of interest, since it has become customary, particularly amongst geneticists, to use this test as a method of combining the results of a number of experiments of the quantal ("all-or-nothing") type involving two treatments only, e.g., differences in mutation rates under two different treatments. Other methods of combining the data which are more efficient and also more satisfactory in other ways are available, but it is difficult to get such methods adopted unless convincing proof of the inefficiency of the combination of probabilities method can be advanced. The results of these computations will enable us to do this.

The general routines already developed include a "programming" routine (F. Yates and S. Lipton) and a set of routines for floating binary operations (S. Lipton). The former inserts the appropriate address in a skeleton programme and punches out the final routine for immediate use, thereby considerably lessening the work required to write a programme and reducing the potentialities of error; this is of considerable importance with the 401, as with the two-address system used in the machine the ordinary system of programming is a tiresome and tedious operation and one which is peculiarly liable to give rise to errors. The routines for floating binary operations allow the full 9-significant-decimal accuracy of the machine to be utilized and accommodate numbers in the range $10^{\pm 8000}$.

On the mechanical and electronic side a good deal of development work, much of it associated with the ancillary equipment, has been undertaken (D. H. Rees and H. G. Carpenter). The facility to type or punch out the results according to instructions contained in the programme is now available. Reorganization and supplementation of the existing input and output equipment is under way. We are also investigating methods of reading information into the

machine directly from Hollerith cards and of punching out information directly from the machine on to Hollerith cards. These two features are of great importance in statistical work, first, because many simple arithmetical operations require to be performed on data which can then be efficiently analysed by punched-card machines, and secondly, because a great deal of data which can best be analysed on electronic machines at present exists on punched cards. When these developments have been completed the computer should play an important part in the better analysis of survey data.

As a result of the first 9 months' experience it may be said that :

(*a*) Having an electronic machine on the spot has made all the difference to developing its applications to research statistical problems. In this respect our experience is exactly parallel with our experience with Hollerith equipment, where we found that it was only by having equipment on the spot, so that research workers could themselves use it, test out different methods and examine the results as they were obtained, that we could exploit its full potentialities.

(*b*) The introduction of electronic methods of computation will make available for regular use statistical methods which at present are scarcely used because of the heavy numerical work involved. This in turn is likely to lead to major developments in method. It will also facilitate and speed up the routine analyses which are at present done on desk machines, but which are of a sufficiently standard type to be programmed electronically, and enable a much more thorough preliminary examination of the data to be made (to check for gross errors, inconsistencies, etc.) than is at present customary or possible.

Design and Analysis of Experiments

The work on the amount of experimentation that is economically justified was brought to a conclusion by P. M. Grundy before he left, but the final details of the full paper on the subject have yet to be settled. M. J. R. Healy and D. H. Rees have co-operated in this work. The joint paper by Grundy, Healy and Rees which was presented to the Biometric Conference in 1953 has now been published (180).

A good deal of work has been done on the reorganization of the long-term and classical Rothamsted and Woburn experiments. H. D. Patterson has been particularly concerned with this work, and with the design and analysis of long-term experiments at Rothamsted and elsewhere. E. M. Crowther's sudden death has placed an added burden on the Statistics Department in connection with this and other work.

There has been the usual volume of routine work on the design and analysis of field and laboratory experiments for Rothamsted and other research stations and for the National Agricultural Advisory Service.

Surveys

During the autumn of 1953 and the first half of 1954, at the request of the Agricultural Research Council and the Ministry of Agriculture, a survey was undertaken by officers of the Ministry's Advisory Land Service and the National Agricultural Advisory Service of a sample of farms assisted under the Hill Farming and Livestock Rearing Acts, and of other farms not assisted under these Acts. The main aims of the survey are to estimate the returns being obtained from public and private expenditure already incurred under the Acts, and to discover what scope there is for further expenditure on upland farms. The survey has been designed by D. A. Boyd and B. M. Church in collaboration with Professor Ellison, University College of Wales, Aberystwyth, and the results have been analysed by the Department (B. M. Church, W. J. Lessells and Muriel E. Davis). The findings will be published in due course.

The survey of fertilizer practice continued in 1954 in twelve districts, the field work being undertaken by the staff of the Advisory Chemists of the National Agricultural Advisory Service. Most of these districts had already been surveyed in recent years, and the combined results will therefore give useful information on trends in fertilizer use. The completion of field work has been delayed; a report will be produced early in 1955. B. M. Church is in charge of this work.

In 1952 estimates were obtained by survey methods of the extent of the loss in yield of winter wheat due to the grazing of rabbits. This was shown to be most severe when the rabbits grazed in January. The estimates were, however, somewhat imprecise because of the restricted size of the survey, and in addition they could not be regarded as national averages because several cereal-growing areas had not been surveyed. A second survey, planned by this Department (M. H. Westmacott) in collaboration with the Ministry of Agriculture and Fisheries Plant Pathology Laboratory, will show whether similar results are obtained in the two seasons, and will improve the precision of estimates by providing a greater body of data. The 1954 survey covered the whole of England and Wales except for the areas where very little winter cereal is grown. Results will be available for analysis during 1955. In view of the very variable incidence of myxomatosis and its incidental effect on rabbit trapping, it may well be advisable to repeat the survey in 1956.

The survey of diseases of dairy cattle (F. B. Leech in collaboration with Dr. F. W. Withers) has been extended to cover Salop and the principal dairying areas of Ayrshire and Lanarkshire, besides continuing the work in Wiltshire, Devon, Surrey and Berkshire. The results of work in Wiltshire, Surrey and Berkshire in 1952–53 have been analysed, and Withers is writing a report.

The results of the 1953 survey of losses in pregnant ewes in Yorkshire have been analysed and a report submitted for publication by Dr. H. C. Sellers and F. B. Leech (186). They showed that although losses were not on the average high, a number of flocks were seriously affected. Flocks in the Holderness region were seriously affected by deaths during pregnancy and at parturition; flocks in the Wold by abortion; flocks in the North-Eastern Moors by barrenness. The survey was repeated during the 1954

lambing season, and the data have arrived for analysis. Weather during the 1953 lambing season was exceptionally favourable; losses during the severe 1954 season may therefore be much greater if weather is a contributory factor. Similarly, if the incidence of barrenness is affected by weather conditions during tupping time there should be relatively little barrenness in 1953–54, for the autumn of 1953 was very mild and the autumn of 1952 very severe.

A paper on some results of the survey of methods of milk production has been completed by F. B. Leech, with Messrs. J. W. Egdell, P. Heskin and S. B. Thomas (185).

On the theoretical side P. M. Grundy prepared a paper on a method of sampling with probability exactly proportional to size (181), and B. M. Church completed an extensive investigation into problems of sample allocation and estimation in an agricultural survey using the data of the survey of fertilizer practice (178).

Colonial Work

A training course in sampling theory and practice, mainly for officers in the Colonial Service, was held at Rothamsted from 23 August to 8 October. This course was organized by the Rothamsted Statistics Department and the Division of Research Techniques of the London School of Economics. The course appears to have been highly successful.

G. E. Hodnett has continued his work in advising and assisting Commonwealth workers, particularly in the Colonial territories, in statistical problems. Seven colonial workers have stayed in the department for periods up to 3 months, and nine others have paid brief visits.

Other Work

M. J. R. Healy has assisted in a number of miscellaneous statistical investigations (183, 184, 121). He contributed a paper on statistical techniques for inspection sampling to *Tropical Agriculture* (182). He has also co-operated with the Meteorological Office at Dunstable on the analysis of long-term weather data on our Hollerith equipment. B. M. Church assisted Mr. A. H. Strickland in a problem of sampling cabbage aphid populations on Brussels sprouts (179).

Various members of the department have co-operated in refereeing scientific papers. In many cases direct advice and assistance have been given to the authors concerned on the better statistical treatment of their data.

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: F. Yates (Chairman in place of Dr. E. M. Crowther), H. V. Garner (Secretary), F. C. Bawden, H. H. Mann, J. R. Moffatt and D. J. Watson. Following the death of Dr. E. M. Crowther, R. K. Schofield and R. G. Warren were appointed to the Committee.

Three Working Parties were constituted to prepare material for the Plot Committee: Classical and Long-Period Experiments (Chairman F. Yates), Pathology Experiments (Chairman F. C. Bawden) and Agronomy Experiments (Chairman D. J. Watson, in place of E. M. Crowther).

The number of plots comprised in the field experiments at Rothamsted and Woburn in 1954 were:

	Grain	Roots	Hay	Grazing	Total
Classical experiments					
Rothamsted	125	72	47	—	244
Woburn	36	—	—	—	36
Long-period experiments					
Rothamsted	371	320	240	96	1,027
Woburn	133	266	55	12	466
Annual experiments					
Rothamsted	399	337	128	—	864
Woburn	40	32	—	—	72
Total	1,104	1,027	470	108	2,709

Some of these plots were put down for observation only, but 2,636 were harvested. In addition, some 420 microplots were carried out at Rothamsted by members of the Chemistry Department on phosphatic fertilizers and fertilizer placement; and the Garden Plots Committee was also responsible for about 360 microplots mainly conducted by the Plant Pathology and Botany Departments. At Woburn Dr. Mann had forty microplots, mostly on exotic crops.

The weather conditions affecting agricultural operations are described in detail in the report on the farms; the following brief notes put on record the main features of 1954 to provide a general background for the year's experimental work.

The autumn of 1953 was extraordinarily mild; the mean temperature in November was 3° F. above the 75-year average and in December almost 5° F. above. Christmas day was 2° F. warmer than Coronation day (2 June). Not only was the weather warm, but November and December were rather dry. The result was that the experimental wheat and beans were drilled in the third week of October, got away well and made much growth in late autumn; this was particularly true of beans. Winter came suddenly at the turn of the year; the whole of January was very cold, particularly the last week of the month. The frost continued into the first week of February when with north-east winds some very low temperatures were reached and even potatoes stored in the buildings suffered. This cold spell blackened the wheat on most of the fields, but did

no permanent damage. The winter beans, on the other hand, were badly thinned, and a small area had to be ploughed up. The remainder came to a useful crop, but they yielded less than the spring sowings.

The thaw came in the second week of February, and for the next 4 weeks it was wet and cold. Spring sowings started in the second week of March, and good use was made of 10 days' dry weather. Rain came again for the last week in March, and sowings were held up, but April was exceptionally dry, with only 0·3 inches for the whole month. Corn sowings were completed by 9 April, when Agdell field went in in a rather rough tilth. An absolute drought was declared on 21 April, but the dry weather enabled work on roots and potatoes to continue without a check. Northerly winds and cold nights made growth very slow at this period.

The months of May to August inclusive provided the worst summer for many years. Each month had more than average rainfall and much less than average sunshine; the total excess rain for the 4 months was 3·98 inches, with a deficiency of 234 hours sunshine. Temperatures also were well below normal. A torrential downpour on 5 June reduced the surface of all exposed land to a slurry. There was no May flush of grass, hay-time dragged on week after week, and although the plots were secured, some commercial hay had to be abandoned. The corn ripened slowly, and there was bad lodging in some of the barley; the Highfield barley plots were so badly lodged that they were not weighed. The newer wheats stood well, but Squareheads Master on Broadbalk was very badly down. Harvest started on 25 August, and was not completed until the middle of October. All the experimental plots that were of suitable shape and size were harvested by combine, using the dryer when required. Consequently, in spite of the very late harvest, the Statistics Department received the field results for analysis earlier than usual.

Potatoes grew well, though there was a low plant population on some experiments. Late blight was unusually bad this season, and the routine copper spraying increased yields considerably. October was a pleasant month, below average rainfall and much above average temperature. Conditions were excellent for potato lifting, and a relatively early start was made on Barnfield mangolds, where work progressed well in spite of several wet days in the early part of November. Sugar-beet lifting was a particularly unpleasant job this year; it was held up by long periods of heavy rain at the end of November, and not completed till 10 December.

As might be expected, 1954 was a weedy year. The root land was frequently too wet to hoe, weeds grew through the lodged corn and there was an amazing growth of green stuff on potato ridges in the warm autumn weather.

The Classical Experiments

The main point of interest in 1954 was the beginning of a liming programme which will shortly embrace all the classicals (except Park Grass), including the permanent wheat and barley at Woburn. At present Broadbalk, Hoosfield, Agdell field and the Exhaustion land have been limed. The details are reported in a separate

section of this report. The main agricultural points in connection with the classical experiments are given below.

Broadbalk

The wheat crops on Broadbalk showed no unusual features. There was rather more weed than in recent years, particularly bent grass, may weed and buttercup. Poppies, which had been a serious pest when the field was in continuous wheat, were beginning to show up again. The most conspicuous change, however, was the increase of wild vetch, which now completely dominates the wheat on Plot 5 (minerals without nitrogen), especially on Section 1. This weed also appeared on Plot 18, Section 5, which had no nitrogen in 1954. Once again wild oats were very thoroughly pulled before they had a chance to seed.

On part of Section 4 under bare fallow an experiment was begun to measure the damage caused by wheat bulb fly. Certain areas of the fallow were covered to prevent egg-laying, and these will serve as non-infected controls in next year's wheat. Other small non-experimental areas in Broadbalk were also used for field investigations on wheat bulb fly.

Owing to the wet weather Broadbalk was lodged worse in 1954 than for many years. Section 5 after fallow lodged very early, and the weeds grew through the fallen crop; this area was therefore unusually weedy at harvest-time. The crop ripened very late. Cutting did not begin until 30 August, and even then the plots without nitrogen were not ripe.

Hoosfield

The barley was even and rather above average in growth, but wild oats were so prevalent in early summer that it was decided to cut the whole produce green and sacrifice the yields. As it turned out, it became possible to provide a team of pickers for this field who worked to such good purpose that the crop was saved for a very late harvest. The plots stood well, only the dung plot was lodged. The barley was not cut until 16 September.

From the appearance of the edge rows of certain plots without phosphate it had been suspected for many years that there had been a transport of fertilizer across the longitudinal pathways from one plot to the next. A set of very detailed sampling traverses of soil and crop were put in hand by the Chemical Department to test this point.

Barnfield

The February frosts and dry weather in April enabled the roots to be sown early in a good tilth, and a good plant of mangolds and sugar beet was obtained. A complete plot-by-plot sampling for sugar-beet eelworm (*Heterodera schachtii*) was carried out just before drilling. Growth was slow and poor all through the season. A good deal of hand work was put into the crop during the summer, and most of the weeds were kept in check. The worst weed is " twitch " (*Agropyrum repens*), which is now very serious on the dung Plots 1–0 and 2–0, and spreading over the lower end of the field. As in the previous wet summer of 1953, the nitrate plots failed to show

their usual superiority over the sulphate of ammonia plots. Yields were much below average in this very sunless season.

Park Grass

The cold spell in February killed off much of the Yorkshire Fog on the unlimed ends of Plots 10 and 11, leaving bare patches, but these were in part filled up by new seedlings by cutting time. Haymaking dragged on for 3 weeks, and the quality of much of the hay was very poor, although the bulk was above average. The warm, moist autumn produced an unusually heavy second crop, with very heavy new growth of Yorkshire Fog on the acid plots. The crop was cut in the middle of November, and carted green under very wet conditions.

Agdell

In preparation for a new long-period experiment it was decided to grow barley once more on this field. Certain acid areas were limed in the winter of 1953–54, and all plots received 2 cwt. of sulphate of ammonia per acre. The seed was sown on 9 April and came up well, but the crop made very slow growth and looked exceedingly poor in early summer. A further 3 cwt. of sulphate of ammonia was top dressed on 18 June, but although growth was more even than in the previous year, it was decided that it was neither level enough nor good enough to provide a useful measure of soil uniformity within the old plots. No yields were therefore taken.

Exhaustion Land

A good plant of barley was obtained which showed in the early stages the usual retardation and deficiency symptoms on plots which had no superphosphate or no dung in the original experiments. As usual, these symptoms were less noticeable in mid-season, but differences in maturity appeared later on. Exhaustive soil sampling was again carried out by the Chemistry Department.

Liming Programme for the Classical Experiments *

Soil acidity

During the early spring of this year the effect of acute soil acidity on the autumn-sown wheat of Broadbalk was seen for the first time. The effect was confined to two small areas, approximately 10–20 sq. yd., in Section 5 of Plots 8 and 14, both of which receive ammonium sulphate. On Sections 1–4 of these plots and also on other ammonium sulphate plots the crop appeared to be normal. Areas of acidity have now developed on parts of all the arable fields of the classical experiments. On Plot 5A, Hoosfield, and Plot 1, Agdell, it was sufficiently acute to cause a failure of the barley crop.

Detailed pH and calcium carbonate maps have recently been prepared for Broadbalk, Agdell, Hoosfield and the Exhaustion Land, and these have several features in common. In all four fields there is a calcium carbonate gradient. On Broadbalk it runs diagonally from a level of 3 per cent $CaCO_3$ on Plot 2, Section 1, down to below 1 per cent on Plot 19, Section 5. On Hoosfield the gradient is also

* Field plans giving plot numbers are given in the Guide to the Experimental Farms, 1954.

diagonal, with a calcium carbonate value of about 2 per cent on Plot 1–0 and virtually none at the opposite corner of the experiment. For both Agdell and the Exhaustion Land the gradients are along the length of the experiments, with the higher level at the east end of the Exhaustion Land, 1·5 per cent $CaCO_3$, and at the north end of Plots 5 and 6, Agdell, with 3 per cent $CaCO_3$. Superimposed on the calcium carbonate map for each field is the acidifying effect of the ammonium sulphate treatments, lowering the amount of calcium carbonate in the soil at the higher level and producing acidity at the other end of the field. The lowest pH values reached are 4·5 on Broadbalk and Hoosfield, and 4·8 on Agdell, where less ammonium sulphate has been applied. On the Exhaustion Land the largest effect of ammonium sulphate occurs on Plot 6 with pH 5·2. This is mainly the result of annual dressings given as a test treatment from 1856 to 1900, but part is due to the basal dressings of ammonium sulphate applied to the whole field from 1941 onwards. The pH map of this field shows an area of more acute acidity at the outside edge of Plot 2, but this is not related to any known manurial treatment. This area does in fact coincide with the extra land brought into the experiment when the site was extended in 1876, at the time of the change from a wheat to a potato experiment, and the present acute acidity must arise from initial acidity in this area.

One other manurial treatment, rape cake, has increased the loss of calcium from the soil. The maps of Broadbalk and Hoosfield and a preliminary survey of Barnfield show that its acidifying effect is less than that of ammonium sulphate. So far there have been no visible symptoms in the crop due to the acidity arising solely from rape cake. While the prominent areas of acidity on all the arable fields of the classical experiments can be ascribed to ammonium sulphate and rape cake, areas with very low calcium carbonate and others with slight acidity are developing on other plots where the initial calcium carbonate must have been low.

Liming

The arable experiments will rapidly lose their value through crop failures and weeds as the areas of acute acidity expand under the traditional scheme of manuring. No useful purpose can be served by continuing to demonstrate the acidifying action of ammonium sulphate. The Field Plots Committee therefore recommended that the fields should be limed and submitted detailed proposals for the liming of Broadbalk to the Lawes Trust Committee. These were approved, and sanction was also given to proceed with the liming of the other fields. Broadbalk and Agdell have now been limed, and the main part of the programme for Hoosfield and the Exhaustion Land has been carried out. Ground chalk was used throughout. It is hoped to complete the pH and calcium carbonate maps for Barnfield and the Wheat and Fallow experiment during the spring of 1955 so that these fields, the last of the series, can be treated next winter.

The " liming " proposals were designed to achieve two main objectives. The first was not merely to destroy acute acidity but to restore each field to a condition such that all parts would have at least a small reserve of calcium carbonate. This would bring the fields more into line with the major part of their history than liming to pH 6·5. Dressings of ground chalk up to 5 tons/acre, part to be

ploughed in and part worked into the seedbed, were therefore recommended for acid areas and also those on the verge of acidity. The second objective was to prevent the re-development of acidity on the plots receiving ammonium sulphate and castor meal, formerly rape cake. In future these two treatments will be modified to include a supplement of chalk. The amount of the chalk supplement for ammonium sulphate is based on the theoretical maximum acidifying action of this salt, for which two molecules of calcium carbonate would be required for each molecule of ammonium sulphate. In practice, it has been found that the ratio of calcium carbonate lost to the ammonium sulphate added is less than this, so the chalk supplement recommended may even result in a very gradual build-up of calcium carbonate. The chalk supplement for castor meal has been calculated on a similar basis. The two stages in acidification by ammonium sulphate, namely the formation of calcium sulphate and the nitrification process, each, in theory, requires the same amount of calcium carbonate, but only the second occurs in the decomposition of castor meal. The chalk supplement for castor meal will therefore be given at half the calcium carbonate : nitrogen ratio used for ammonium sulphate.

The main points of the liming programme for each field are as follows :

Liming programme for the arable fields of the classical experiments

A. *Single applications of chalk*

	Area limed	$CaCO_3$, tons/acre
Agdell	Plot 1	3
	Plot 2	4
	Plot 3 part only	0·5
	Plot 4 parts at	0·5, 1·0 and 1·5
Broadbalk	Section 5b (the strip nearest the drain)	5
	Section 5a has been left unlimed for observation but will be reconsidered for liming if the rate of recovery from acidity on Plots 8 and 14 after several applications of the supplementary chalk dressings is not satisfactory.	
Hoosfield	Strips 3 and 4 including Plots 5O and 5A	5
Exhaustion Land	Plot 1 N.W. corner	2
	Plot 2 north side	5
	Plot 2 central strip	2
	Plot 4 parts at	2 and 3
	Plot 6 part only	4
	Plot 8 part only	3
	Plot 10y	2

B. *Repeated applications of chalk*

On Broadbalk and Hoosfield chalk supplements will be given to plots receiving ammonium sulphate and to those receiving castor meal. The rates of application will be,

100 lb. $CaCO_3$/14 lb. N as ammonium sulphate.
50 lb. $CaCO_3$/14 lb. N as castor meal.

In the first year of the modified treatments on Broadbalk the supplements will be at double rate to assist recovery of some of the acid plots. In succeeding years the annual supplements will revert to the standard rate. No supplement will be given on Broadbalk to the section that is fallowed. On Hoosfield the supplements will be applied once every 5 years at five times the annual rate.

Long-period Experiments

The four-course rotation testing residual effects of organic manures and phosphatic fertilizers completed its last year under the original scheme in 1954, and an account of the results will be found on p. 153 below. The experiment is to be continued in a modified form on the old plots. The six-course rotation measuring the responses of six crops to each of the three main nutrients was continued for the twenty-fifth season at both Rothamsted and Woburn. The new three-course rotation, modified to analyse the effects of raw straw on the land, completed its third season, but calls for no comment at this stage.

The ley–arable rotation experiment on Highfield and Fosters completed its first full six-year cycle on those blocks that were started in 1949; barley, the third test crop, being grown for the first time. Unfortunately, the residual fertility after old grass on Highfield was sufficient to lodge the barley so severely in the exceptional weather of 1954 that no yields could be obtained. On the old arable land on Fosters field, barley yields were measured. Turning now to the " treatment " crops, the characteristic of the herbage crops in 1954 was a reduced spring flush of vegetation; growth was steady rather than rapid. On Highfield, grazing began on 13 April and continued till late in October, but on Fosters field, which is more exposed, the stock were not admitted until 6 May. A greater number of grazing days was recorded for Highfield, but this was not entirely accounted for by the earlier start. The Highfield grasses, particularly the leys, were also more productive than their counterparts on Fosters. Thus the first year of the ley was much better on Highfield than on Fosters, where it was poor and weedy, and only gave about three-quarters of the output. The lucerne was good on both fields, the main difference being that on Highfield the third-year stand was as usual very grassy, and this probably affected both yield and quality. Apart from this, lucerne was as usual a very successful crop, and with a yield of about 5 tons of dry matter per acre, was by far the most productive herbage crop grown. The cut-grass gave a normal crop, and the extra nitrogen, while it increased the yield, noticeably depressed the clover in the mixed herbage.

The yields of the various herbage crops will be found in terms of cwt. dry matter per acre in Table 1 on p. 150.

The test crops of 1954 measured the effects of 3 years of cropping with various leys or arable crops. The yields are given in Table 2, below. In the wheat crop in Highfield only the plots after cut-grass were in any way remarkable. In the winter months the tilth on these plots looked rough and turfy, the plant was backward at the end of May, and rusty looking in August. The yield was 10 cwt./acre less than that of the wheat after lucerne. This result is in line with previous observations. On Highfield all the plots were badly lodged, and there was considerable damage from birds, with the result that the mean yield was only 28 cwt./acre, 10 cwt. less than in the previous two years. For wheat which already received 2 cwt. of " Nitro-Chalk " per acre, an extra 2 cwt./acre of " Nitro-Chalk " was harmful rather than beneficial.

The corresponding wheat crop on Fosters was a better one,

TABLE 1

Rothamsted ley–arable experiment, Highfield and Fosters, 1954

Yield of dry matter, cwt./acre

	Old grass		Reseeded grass		3-year ley	Cut	Cut	1-year ley
	Hay	Grazing	Hay	Grazing	Grazing	grass	lucerne	hay
Highfield								
Blocks :								
First year ..	—	39·9	—	48·7	43·3	82·3	58·8	63·1
Second year	—	36·6	—	44·1	45·7	67·2	103·8	—
Third year	45·9	20·2*	55·5	19·2*	46·2	65·1	100·0	—
Fosters								
Blocks :								
First year ..	—	—	—	41·5	30·8	67·7	57·5	60·9
Second year	—	—	—	43·7	46·9	73·8	97·5	—
Third year	—	—	49·3	20·2*	35·1	70·0	94·4	—

* Aftermath grazing.

averaging 35 cwt. grain per acre; here the weakest crop was the one following the arable rotation, for it gave 12 cwt. less than any of the crops after ley. This is the first season in which the wheat in the purely arable rotation has done noticeably worse than wheat after leys. The result is probably due to eyespot disease, which has gradually increased where three susceptible cereal crops are

TABLE 2

Yield of test crops, 1954

	After 3 years' cropping with :				
	Lucerne	Grazed ley	Cut grass	Arable crops	Mean
First test crop:					
Wheat, grain, cwt.					
Highfield	28·6	32·7	22·7	27·9	28·0
Effect of 0·3 cwt. N ..	−1·7	−4·2	−4·2	−1·5	−2·9
Fosters	37·4	39·5	38·2	24·7	35·0
Effect of 0·3 cwt. N ..	2·7	3·9	−0·4	1·7	2·0
Second test crop:					
Potatoes, tons					
Highfield	10·46	11·03	10·41	10·68	10·64
Effect of 12 tons dung ..	3·14	3·70	3·08	4·17	3·52
Effect of 0·5 cwt. N ..	1·16	0·25	−0·01	0·53	0·49
Fosters	10·20	10·18	9·51	10·85	10·18
Effect of 12 tons dung ..	5·22	1·89	3·54	2·20	3·21
Effect of 0·5 cwt. N ..	1·24	1·10	0·58	1·35	1·07
Third test crop:					
Barley, grain, cwt.					
Fosters	45·7	44·0	44·6	44·7	44·8
Effect of 0·2 cwt. N ..	−1·8	1·0	0·3	0·9	0·1

grown in 6 years. In 1952 and 1953 the disease was not prevalent enough to cause appreciable loss in grain, but in 1954, 90 per cent of the straws of wheat following the arable rotation had eyespot lesions, 69 per cent being severe. At harvest, 80 per cent of the area of these plots was completely lodged, and grain yields were between 11 and 12 cwt./acre less than in the two previous years, when there was little eyespot and no lodging. By contrast, plots of

wheat following 3 years lucerne, grazed ley and cut-grass had respectively 11, 3 and 4 per cent straws with severe lesions in 1954. They were not lodged, and gave much the same yield as in the two previous seasons.

The wheat on Highfield differed from Fosters in that eyespot occurred on only 21 per cent of the straws of wheat following the arable treatment, 13 per cent having severe lesions, and this was not appreciably more than in previous years. The difference in incidence between the two fields may be related to their previous history, for Highfield was under grass, whereas Fosters was under arable cropping in which cereals predominated. On Fosters field extra "Nitro-Chalk" was beneficial.

The potatoes were fairly good on both fields, and showed the usual benefits from dung and to a lesser extent from the higher level of nitrogen. Barley, the third test crop, was too badly lodged on Highfield to measure for yield, but on Fosters the crop was excellent and so uniformly good that no response to any of the treatments was observed.

Annual and Short-period Experiments

The **annual experiments** were mostly repetitions of former experiments on new sites.

(1) Wheat, West Barnfield I. Residuals of dung and fertilizers applied to the previous potato crop. For the first time this experiment tested the residual effects of the three main nutrients in addition to that of dung. The wheat yielded 40 cwt. of grain in 1954. Ten tons of dung applied to the potatoes of 1953 gave an increase of 4·2 cwt. grain in the following wheat crop, a result in line with previous findings. In this experiment 2 cwt. muriate of potash also had a beneficial effect. Sulphate of ammonia at 3 cwt./acre applied to potatoes also showed up in the wheat, a somewhat unusual result, which needs confirmation.

(2) Barley, Long Hoos V. Effect of levels of seedbed nitrogen and rates of seeding on lodging. This experiment is discussed in the report of the Plant Pathology Department.

(3) Potatoes, Sawyers I. Effect of dung and fertilizers. As in former years this experiment gave good responses to dung, nitrogen and potash. The full potash requirement of the crop this season was met either by dung (10 tons) or by potash (2 cwt. muriate), i.e., neither of these materials gave an increase in the presence of the other. Superphosphate was effective only in the presence of nitrogen.

(4) Experiments on wheat and barley tested the Massey Harris 780 forward-cut combine against the binder for harvesting experimental plots of various shapes and sizes. The combine proved quite satisfactory in these tests, and in future as many experiments as possible will be handled by this method.

Many of the **short-period experiments** were carried out by or on behalf of the scientific departments. The yields are fully dis-

cussed by the departments concerned. The chief experiments are listed below.

Fertilizer placement experiments (G. W. Cooke, Chemistry Department)

(1) Lucerne—Highfield V, third year; residuals of treatments applied in spring 1952: superphosphate, muriate of potash, broadcast or ploughed in, with or without a " starter " of superphosphate placed beneath the seed. In June 1954 muriate of potash as top dressing was compared with muriate of potash as foliage spray.

(2) Potatoes—Deacon's Field; all combinations of three levels of sulphate of ammonia and three levels of muriate of potash, the constituents being either broadcast or placed.

Plant pathology experiments

(1) Eyespot in wheat (M. D. Glynne)—Little Knott, fifth year; Cappelle wheat at two seed rates on plots which had formerly carried thirty-two different crop sequences.

(2) New eyespot rotation—Long Hoos II and III; started in 1954 on land only lightly infected with eyespot. First preparatory year. In 2 years four crop sequences will be set up whose effects will be tested in wheat in 1956. The wheat crops of 1954 occupied eight blocks, testing two varieties (Cappelle and Holdfast), two rates of sowing and two quantities of nitrogen top dressing.

(3) Eyespot and take-all (G. A. Salt)—Roadpiece, Woburn; test of two varieties (Cappelle and Holdfast), two rates of sowing, two quantities of nitrogen and four times of applying nitrogen.

(4) Potatoes, control of late blight (J. M. Hirst)—Great Field I; effect of copper spraying and burning off with sulphuric acid on yield of Majestic potatoes and incidence of blight (*Phytophthora infestans*). Determinations were also made of the loss of yield due to the passage of spraying machinery through the crop.

(5) Potatoes, virus spread (L. Broadbent)—Great Field I; effect of four insecticidal treatments, each applied at frequent intervals during the growing season on spread of two viruses introduced by infector plants.

(6) Broccoli, virus spread (L. Broadbent)—Great Knott I; effect of dung and of two rates of " Nitro-Chalk " on yield, quality and spread of cauliflower mosaic virus.

(7) Wheat, wireworm control (F. Raw, Entomology Department, and C. Potter, Insecticides Department)—Geescroft Field, third year; residual effects of five soil insecticides applied in the autumn of 1951 for the wheat of 1952.

(8) Wheat bulb fly (D. B. Long, Entomology Department)—Long Hoos VII, preliminary year; spring wheat at four seed rates was grown in 1954 to provide different degrees of ground cover.

(9) Beans, control of aphids (M. J. Way, Insecticides Department)—Little Hoos; test of four insecticides on autumn-sown and on spring-sown beans.

Four-Course Rotation

Summary of Results, 1930—1954

The site of the four-course rotation is an area of about 3 acres lying between two much older experiments, the Hoosfield permanent barley plots, to the south, and the alternate wheat and fallow plots, to the north.

The soil is a clay loam which was heavily chalked, probably in the early years of the 19th century. Most of the area still has substantial reserves of calcium carbonate, but at the East end there are patches that are now becoming acid.

For 64 years, commencing in 1847, this land had carried manurial experiments on various leguminous crops grown continuously. The effects of these crops and manurial treatments were then measured in a long series of barley test crops which continued until 1929, when the four-course rotation experiment was laid out to measure the first year and residual effects of three bulky organic manures based on straw and two phosphatic fertilizers. The sequence of crops was potatoes, barley, autumn-sown ryegrass, wheat. A block of twenty-five plots was assigned to each of these crops, and thereafter the four crops rotated on their respective blocks, every crop being grown each year. The organic manures and phosphatic fertilizers whose residual effects were to be measured were dung, straw compost, raw straw, superphosphate and rock phosphate, and they were applied cumulatively on their respective plots once every 5 years. With a 5-year fertilizer period and a 4-year crop rotation the full cycle of the experiment was 20 years.

All plots received 1·8 cwt. N, 1·2 cwt. P_2O_5 and 3·0 cwt. K_2O over the 5-year period. The dung and compost provided 50 cwt. of organic matter per acre, while the quantity of raw straw was such that it would have given 50 cwt. of organic matter if it had been rotted in the compost heap. As much as possible of the nutrients was supplied in the form of the experimental manures and fertilizers, the balance necessary to make the total up to specification being given as sulphate of ammonia, superphosphate and muriate of potash.

The plots testing the phosphatic fertilizers received their supplementary nitrogen and potash not in a single dose with the phosphate, but in five yearly dressings totalling up to the full amount. This distribution of nutrients throughout the rotation instead of a single large initial dose was undoubtedly beneficial as far as nitrogen was concerned. The composition of the manures altered considerably from year to year, for example the dung dressings ranged from 6·6 to 20·5 tons/acre, but the average dressings required to provide the standard amount of nutrients were :

Quantities applied per acre once in 5 years

Manures or fertilizers on test		Supplementary fertilizers, cwt.		
		Sulphate of ammonia	Super-phosphate	Muriate of potash
Farmyard manure ..	13·6 tons	1·18	2·79	1·63
Straw compost	14·8 ,,	2·11	1·72	3·90
Straw	7·4 ,,	4·97	5·15	2·38
Superphosphate	6·2 cwt.	1·72*	—	1·00*
Rock phosphate	4·3 ,,	1·72*	—	1·00*

* Annual dressings.

In terms of nutrients the above dressings provide the following quantities in cwt./acre :

	Main dressings			Supplementary fertilizers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Farmyard manure ..	1·56	0·68	2·05	0·24	0·52	0·95
Straw compost ..	1·36	0·38	0·79	0·44	0·32	2·21
Straw	0·76	0·26	1·69	1·04	0·94	1·31
Superphosphate ..	—	1·20	—	0·36*	—	0·60*
Rock phosphate ..	—	1·20	—	0·36*	—	0·60*

* Annual dressings.

In 1942 and subsequently all the potato plots were split to test the effect of an extra 2 cwt. of sulphate of ammonia (0·4 cwt. N) per acre. It will be noted that there are no plots which never receive phosphate, but forty plots never have any organic material.

Application of manures

All organic manures were spread in autumn and ploughed in ; the quantity of straw was so large that it was chaffed and laid down each furrow.

The supplementary artificials for the dung and straw compost were broadcast and ploughed in with these organic manures. In the case of straw the amount of supplementary nitrogen was so large that the supplementary artificials (NPK) were applied in three equal dressings, the first ploughed in in winter, the second and third broadcast in the spring by methods suited to the individual crops.

The inorganic fertilizers (NPK) were broadcast over the ridges for potatoes, and thus gave a " placement " effect in the first phosphate year that was not repeated in the residual years. The extra nitrogen for potatoes was also given in the ridges.

Once in 4 years each of the blocks has a " maintenance " lime dressing of 10 cwt. CaO per acre ploughed in for the barley crop.

Four-course Rotation, Rothamsted

Summary of results to 1954, twenty-one seasons

Years after application	Farmyard manure	Straw compost	Raw straw	Super-phosphate	Rock phosphate	S.E.
Potatoes, tons/acre (no additional N)						
0	6·41	6·18	6·89	6·90	4·49	±0·18*
1	5·35	4·92	5·01	5·76	4·49	±0·16†
2	5·17	4·47	5·22	5·86	4·69	
3	4·79	4·51	5·10	5·74	4·54	
4	4·58	4·33	4·95	5·60	4·58	
Mean	5·26	4·88	5·43	5·97	4·56	±0·11
Response to 0·4 cwt. additional N per acre, 1942–54						
0	1·49	0·82	1·19	0·78	0·12	
1	1·82	1·47	1·59	1·00	0·81	
2	1·15	1·46	1·53	0·68	0·21	±0·28
3	1·64	0·90	1·08	0·57	0·41	
4	1·54	0·78	1·38	0·75	−0·18	
Mean	1·53	1·09	1·35	0·76	0·27	±0·12
Barley, cwt. grain per acre						
0	28·0	27·5	29·3	27·6	23·4	±0·41*
1	22·8	22·0	22·0	25·8	24·0	±0·48†
2	20·7	19·9	21·2	26·4	25·0	
3	19·0	19·6	20·9	26·4	24·3	
4	18·9	18·6	20·5	25·8	25·6	
Mean	21·9	21·5	22·8	26·4	24·5	±0·31

Years after application	Farmyard manure	Straw compost	Raw straw	Super-phosphate	Rock phosphate	S.E.
Ryegrass, cwt. dry matter per acre, 1935–40, 1942–48, 1950–54						
0	19·2	19·5	30·9	19·5	17·6	
1	12·5	13·1	11·6	19·3	16·7	
2	11·2	10·3	12·6	18·8	17·0	
3	9·6	9·7	10·7	18·0	16·8	
4	9·6	9·8	9·6	18·0	16·6	
Mean	12·4	12·5	15·1	18·7	16·9	
Wheat, cwt. grain per acre						
0	20·9	22·2	23·6	18·7	18·7	±0·31*
1	17·0	17·0	15·9	17·8	18·3	±0·32†
2	15·3	15·0	16·8	18·4	18·2	
3	15·1	15·2	15·7	18·1	18·3	
4	15·2	14·8	14·9	18·6	18·0	
Mean	16·7	16·8	17·4	18·3	18·3	±0·17

* S.Es. for horizontal comparisons.
† S.Es. for vertical comparisons and interactions.

Note: All yields except those of ryegrass have been adjusted for block differences. The adjustment of the ryegrass yields is complicated, and has not yet been carried out; these adjustments are, however, almost certainly small, as they were in the case of the other crops, as each block has in some year carried nearly all of the treatment–phase combinations.

Superphosphate and mineral phosphate

The last column of the main table gives the yields on the plots which received mineral phosphate every fifth year and nitrogen and potash annually. There is no basis for determining the response to mineral phosphate, but it was certainly small as was to be expected since the soil contains calcium carbonate. The substitution of superphosphate for mineral phosphate increased the yields of all crops except wheat. These increases are fair estimates of the responses to superphosphate, even though they may not represent quite the whole of the responses.

Response to superphosphate

(Difference superphosphate—mineral phosphate)

Years after application	0	Mean of 1 to 4
Potatoes without extra N ..	2·4	1·2 tons/acre
Potatoes with extra N ..	3·0	1·6 tons/acre
Barley (grain)	4·2	1·3 cwt./acre
Ryegrass (dry matter) ..	1·9	1·8 cwt./acre
Wheat (grain)	0	0 cwt./acre

With both potatoes and barley the benefit from the superphosphate was especially great in the year of application, but its residual effect was also considerable, and declined little if at all during the 4 residual years. It should be noted that these results were obtained on a soil containing calcium carbonate in which it is probable that surplus phosphate was precipitated as basic calcium phosphate. The inference is that such precipitated calcium phosphate is not wholly unavailable and may give residual effects for many years.

Farmyard manure, straw compost and raw straw

The plots which received farmyard manure, straw compost and raw straw were given all supplementary fertilizers in the same year

and none in the residual years, except that all potato plots were split for extra nitrogen from 1942 onwards. A drop in available nitrogen and potash as well as phosphate may, therefore, have contributed to the falling off in the yields in the residual years. No precise test can be applied, but it may be noted that both with farmyard manure and raw straw the response of potatoes to extra nitrogen in the last residual year was up to the mean for all 5 years. The fall in potash status was evidently too small to influence the response of the potatoes to extra nitrogen. Since the wheat did not respond to phosphate, the grain yields reflect the supply of available nitrogen. The highest yields were obtained in the year of application on the plots which received raw straw and sulphate of ammonia, doubtless because some of the sulphate of ammonia was applied in the spring. The same effect is apparent in the other crops, particularly the ryegrass.

In the residual years the organic manures appear to add very little to the supply of available nitrogen. This conclusion is strongly supported by the handsome response of the potatoes to extra nitrogen. The response to extra nitrogen in the year of application was also large, but is not so well determined, the effect in the residual years being the mean of four values.

The effects of the phosphate added in and with the organic matter are most clearly seen in the potato yields. The drop in yield from the year of application to the residual years on the half-plots which received extra nitrogen averaged 1·4 tons/acre, and was no less than on the corresponding half-plots which received superphosphate alone. Thus there is no indication that the added organic matter has influenced the change which phosphate applied as superphosphate suffered with lapse of time. The straw compost was equal to the farmyard manure for barley, ryegrass and wheat, and nearly so for potatoes without extra nitrogen in the year of application. But both in residual years and with extra nitrogen the straw compost was distinctly less effective than either farmyard manure or raw straw and fertilizer. Half the phosphate given with the compost originated as mineral phosphate, and may have remained undissolved. Of the remainder, half came from the straw and half was added in the supplementary fertilizer, and there may have been insufficient available phosphate to last through the residual years or to permit the full response of the potatoes to the extra nitrogen, even in the year of application. The very small response of the potatoes on the mineral phosphate plots to extra nitrogen shows how this response depends on the availability of phosphate.

THE FARMS

J. R. Moffatt

Rothamsted

The year 1953–54 was a very difficult and disappointing one, mainly because of the very abnormal weather conditions, which caused serious difficulties which were hard to overcome. Yields of most crops suffered, and in many cases the quality was lowered. Each of the main harvesting operations was delayed and was spread over a much longer period than usual. This resulted in considerable overlapping of operations, which in the end upset plans for the autumn sowing of crops for the 1955 harvest. Very little winter corn was sown, and it was not possible to drill any winter beans. There will, therefore, be a big increase in the amount of work to be done in the spring of 1955.

The Effect of Weather on the Crops

The autumn of 1953 and early weeks of January 1954 were much drier and milder than usual; the harvesting of the root crops of the 1953 crops was greatly facilitated, and the winter ploughing for the 1954 crops suffered very little interruption. The mild weather resulted in a prolific germination of weed seeds on the fields which were ploughed early, and several were given a second ploughing.

There was a spell of very hard weather in late January and early February, and for about two weeks the maximum air temperature seldom rose above freezing point. Fortunately, land work was well forward by this time, and little inconvenience was caused. After this spell, weather remained generally mild and wet for the rest of February and early March. This caused the spring sowing season to have a rather late start, but seedbed preparations started about the middle of March, and drilling was completed by the end of the month. The drilling of barley on the Hoosfield permanent barley plots and spring wheat on a non-experimental field was delayed in order to get a good germination of wild oats which could be destroyed before drilling. In this we were successful, but in both cases there was still a heavy infestation in the corn crop.

The month of April was very dry, and the preparation of seedbeds for the root crops and the drilling of these crops was carried out without interruption. By the end of the month drought conditions prevailed, and potato tubers were planted in very dry soil. The dry weather continued until early May and seriously delayed the germination of the root crops, which was very uneven, and subsequent growth was very slow. The potato shoots took a long time to appear above ground, and were far more irregular than usual, and the subsequent plants were less bushy. However, the rate of growth improved later in May after rain had fallen.

There followed a prolonged spell of cold, wet, sunless weather covering the summer months of June, July and August. Rainfall was over 1 inch above normal in each of these months, and there was

a total deficit of almost 180 hours sunshine. Much of the hay crop was ruined, much of the corn became badly lodged and ripening was considerably delayed; growth of the root crops also appeared to be retarded by the lack of sun.

The corn harvest commenced on 26 August, about three weeks later than usual, and became an extremely slow and protracted operation which lasted until about the middle of October. As much as possible of the corn was cut by combine-harvester, but as practically all the combined corn needed immediate drying, the rate of work was restricted to the throughput of the platform drier. Binders were used on some of the upstanding crops, but many of the fields could only be dealt with by combine-harvesters, as early lodging had enabled weeds to grow through the crops, and this greatly complicated the harvesting and drying operations. The straw from the combine was baled and carted in, but some fields have yet to be cleared. Much of it would have been burned on the field, except that this would spoil the uniformity of the fields and render them useless for experimental work for some years.

September and October were comparatively dry months, but even so the rainfall was spread over 20 days of each month. Because of the impossibility of recruiting outside assistance for the potato harvest, we had to rely on schoolchildren working on Saturdays, and in order to get the crop in while soil conditions were reasonable, lifting started before the corn harvest was completed. The work was therefore spread over several weeks, and was not completed until the middle of November.

The very late corn harvest and its consequent overlapping with the potato harvest delayed other autumn land work. Only small experimental areas could be ploughed during October, but many of the winter corn experiments were drilled before the end of the month. It was hoped to complete the winter corn and bean drilling early in November, but adverse weather conditions made this impossible. Rainfall in November totalled 5·31 inches, nearly twice the average, and the ground became waterlogged. Practically no land work was possible during the month, and no drilling was attempted.

December brought an improvement in the weather, and it was possible to continue the drilling of the winter corn during the second week of the month, though soil conditions were far from ideal. Broadbalk field was sown during this spell. After a short wet spell the weather greatly improved, and there was a dry and mild spell. Some few further areas of non-experimental winter corn were sown just before Christmas, and ploughing was pushed on. Good progress had been made by the end of the year, but much ploughing remained to be done in the new year.

Field Experiments

The number of field experiments remained about the same as in the previous year, but despite the adverse weather the programme was not so difficult to execute as in some previous seasons. This was due to the fact that the dry weather in the latter half of March and April enabled the spring sowing to be carried out without interruption, and the use of the combine-harvester on the cereal

plots greatly facilitated and expedited this work. Had we not had this combine, it is doubtful whether all the plots would have been harvested. Certainly the harvest period would have been considerably lengthened, and it would have clashed severely with the harvesting of the root crops. The use of the pick-up baler on the hay plots enabled this work to be carried out expeditiously, and the mounted elevator-type potato digger accelerated the harvesting of the potato plots. Next year it is hoped to deal with the experimental green crops by baling and making into silage, instead of manhandling them all, as is the present practice. However, even with these mechanical aids the programme could not have been carried out without the willing co-operation of all members of the farm staff, who put in long hours of work when conditions allowed. The experiments embraced most farm crops, and an account of them is given in the report of the Field Plots Committee.

Cropping and Rotations

Of the 442 acres which were farmed, 368 were under arable crops, of which about 256 acres were under tillage crops and 112 acres under leys of varying duration. There is still a considerable area of old grassland, much of it unploughable because of tree-stumps, but some is under experiments or is reserved as sites for future experiments. The main tillage crops were wheat 88 acres, barley 85 acres, oats 10 acres, potatoes 25 acres, kale, mangolds and sugar beet 20 acres, and beans 9 acres, while about 12 acres were under fallow or used as headlands on experiments.

The acreage under the various crops was not changed much from previous years, but the area under potatoes was kept as low as possible because of the difficulty in obtaining seasonal labour for lifting. Potatoes are the main cleaning crop of the arable rotation, and the reduction in the acreage may lead to a revision of the cropping scheme. This reduction has brought about further difficulties in that the area of land following a crop other than cereals, which is often required for cereal experiments, is greatly reduced, and suitable sites are more difficult to find. To overcome this difficulty it is proposed in future to extend the area under beans, which crop can be used on the farm or sold. The increase in knowledge of spraying against bean aphis in recent years has made this a far more certain crop than it was. The emphasis is likely to be on spring beans rather than winter beans, because with a very full autumn programme of work it is seldom possible to get the beans sown early enough, the possible loss of plant due to bad weather is eliminated and there is more time in which to clean the land.

Another development which will call for a revised crop rotation has been the scheduling of about eleven fields as sites deficient in phosphate or potash, to which these fertilizers cannot be applied except on experiments. Potatoes cannot be grown as a cleaning crop, as it would be useless to grow this crop without these fertilizers. For the same reason most other cleaning crops are ruled out, and the only effective means of cleaning these areas will be by bare fallow or by the use of short-term leys. Two of these scheduled fields were undersown in 1954 with a 2-year hay or silage mixture.

Use of Sprays

A rather ambitious scheme of spraying against weeds in cereal crops was severely curtailed by the unsuitable weather, which in many instances prevented spraying until the crops were too high for it. However, several fields were sprayed with DNOC mainly against cleavers (*Galium aparine*), or with MCPA against a wider range of weeds which did not include cleavers.

Some preliminary trials with TCA against couch grass (*Agropyrum repens*) were carried out on the headlands of some of the fields, and the results were encouraging. This autumn, therefore, a more ambitious scheme was put into operation in an attempt to clear two fields where the infestation was getting serious. One spraying was done in December, after which the land was cultivated, and another spraying will be done in January if weather conditions permit. Both fields will be cropped with potatoes in 1955.

Crops

Wheat

Of the 88 acres under this crop 72 acres were winter sown and 16 spring sown. Cappelle held pride of place with 56 acres, but a small area of Holdfast was grown for the first time. No lodging occurred in either of these varieties, and most of the fields promise satisfactory yields. They were mostly cut by binder so that the combines could tackle the laid crops. The Holdfast showed some signs of sprouting in the ear before cutting was done, but a nice sample of wheat was obtained. Squareheads Master 13/4 was grown on the classical plots, and on Broadbalk lodging was severe. Yeoman was grown on the long-term rotation experiments. There was little evidence of wheat bulb fly damage on any of the fields.

One piece of Atle wheat was very badly lodged early in the season. Weeds grew up through the crop, and though it was combined, losses were fairly heavy. The grain was badly shrivelled. Another area of the same variety did better, but the small area of Koga II spring wheat grown on an experiment did extremely well. It stood perfectly and gave a heavy yield; the area of this variety will be considerably increased in future.

The infestation of wild oats on Broadbalk field has now been practically eliminated by thorough hand-pulling twice a year for many years.

Barley

Plumage Archer has been replaced by Proctor or Herta barley on all except experimental plots and blanket areas, and many of these were laid. Herta was grown on the richer fields, and though only a modest amount of nitrogen was used, much of the crop was badly laid early on, and a lot of chickweed grew through it, making harvesting a very slow and tedious job. Proctor occupied the biggest acreage. Some areas of this variety stood well, while others were badly lodged, but all the grain not required for sowing ourselves has been sold for seed.

An intensified attack was made during the summer on the wild oats on the Hoosfield barley plots, and all except a few bad patches

were pulled by hand. These bad patches were cut and carted off before the oats seeded.

Oats

The Dutch variety Marne, which yielded so well with us in the last 2 years, was again grown. However, as in 1953, the crop was badly lodged early in the season. It was, however, cut very successfully by the combine, and yielded reasonably well. In future years a rather stiffer-strawed variety will be grown.

Beans

A small area of non-experimental winter beans was drilled, mainly to reduce the possibility of bird damage to adjoining experimental plots. However, the spell of very severe weather during the winter killed off a fair proportion of the plants in one field, and so after a fair seedbed had been prepared by the use of a mechanical weeder, barley was drilled between the rows. This made rather slow growth and had to compete with a rather heavy infestation of black bent (*Alopecurus agrestis*). The beans suffered badly from an attack by bean aphis, so that the resulting crop was very disappointing. The area of spring beans was restricted to experimental plots.

Potatoes

As has been mentioned already, the potato acreage was kept low because of difficulties at lifting time. The year was a very disappointing one for the crop, and the plants never looked really vigorous. This is reflected in the yields, which were several tons per acre below the 1953 yields. As in the past, only one variety, Majestic, was grown, and stock seed was used on all areas.

Planting was done, mainly by a dropper, in good time, but the ground was extremely dry, and this had a very detrimental effect on early growth. During the early summer the cultivations were frequently delayed or prevented by unsuitable soil or weather conditions, and the crops were therefore more weedy than usual. The weather was very suitable for the spread of Late Blight, and two sprayings were done to prevent this. The haulm was later burnt off with acid, which also reduced the weeds. There were few diseased tubers, and the crop is keeping well in the barn at the farmstead. Very few have been sorted so far, but the whole crop has been sold to one firm.

Sugar beet and mangolds

Only the minimum area required for experimental plots was given to these crops owing to their heavy labour demands and the great difficulty in getting them off our heavy land in late autumn. In the early stages the plants were very slow and irregular in growth, and singling was complicated. Subsequent growth seemed slow, and this was probably due to the lack of sunshine. There were rather more bolters than usual in the sugar beet crop, and both yields of beet and sugar content were disappointingly low.

The mangold crop in Barnfield was far cleaner than usual, as owing to the weather in early August preventing any harvest work, the mangolds were given a second hand-hoeing. Yields were lower

than usual, despite the fact that sowing was done earlier than normally.

Both sugar beet and mangolds suffered from an attack by the mangold fly (*Pegomyia betae*) early in the season, and spraying was necessary to prevent the damage reaching serious proportions.

Kale

This is about the only crop which seemed to benefit from the wet season. The seedlings received no check from flea-beetle attack, as some of the seed was dressed against this pest, and an early preventive spraying with miscible DDT was given. The crop made rapid growth throughout the summer. Weed control was made difficult by the wet weather, which enabled many of the weeds to take root again after being horse or tractor hoed, but they were soon smothered by the rapidly growing plant of kale. The crop is now being cut and carted to livestock, and the yield is very heavy.

Grassland

There was very little grass in the early part of the season, as growth was severely retarded by the long spell of cold, dry weather with very low night temperatures during April. The grazing season therefore started very much later than usual, and the normal spring flush was absent this year. However, the grass made better growth in the warmer, damper weather in May, and subsequently maintained good growth throughout the season.

The hay season was the worst for many years. Early growth was very slow, but, as the consistently wet weather prevented any hay being cut until late June, the crop was able to bulk up later. Unfortunately the persistent dull, wet weather made it very difficult to save the crop in anything approaching good condition. Such hay as it was, was baled and eventually carted in. One field of 12 acres was turned so many times, and became so leached and brittle, that it was worthless, and was eventually burnt. Fortunately there was a good stock of hay left from the previous year.

Livestock

Cattle

The policy was continued of buying in young store cattle, wintering them in yards to make farmyard manure, and fattening them from the grass during the summer and autumn. Both Devon and Hereford-cross cattle were used, but because of the late grazing season, most of them were not ready until late autumn.

Sheep

The old ewe flock was sold in 1953 and was replaced by a smaller flock of eighty Scotch Half-bred gimmers. A flock of this size very comfortably provides the requirement of tegs for grazing the experimental field plots. The 1954 lambing season was not very productive, only 110 lambs being tailed from the 80 ewes put to the tups.

Implements

The main purchase during the year was a 10-ft. self-propelled combine, primarily for work on the experimental field plots. This

worked very satisfactorily on both standing and laid crops, and enabled crops to be gathered which would otherwise have been written off as lost.

A tractor-mounted elevator potato digger was bought for use on experimental field plots, and after some initial difficulties, worked satisfactorily. The blade of the machine got under the first few plants in the plot rows more easily than did a similar trailed model, and turning time on headlands of these small areas was greatly reduced.

Several different types of mechanical hedge cutters were tried out during the year, the most satisfactory one being a tractor-mounted machine driven by an auxiliary engine, which needs a man to guide the knife. One of these machines was bought, and in addition to hedge cutting was used to cut kale for carting to stock.

Woburn

The Woburn Farm was directed and managed by the staff of the Rothamsted Farm, but the day-to-day work was planned by the bailiff at Woburn.

1954 was a very difficult year because of the very adverse weather conditions, but the full programme of work was successfully carried out. The effect of the cold, wet summer was less marked on the light land at Woburn than it was at Rothamsted, the main effects being on the root crops, where yields were reduced.

Of the 127 acres farmed, 24 acres were under wheat, 37 under barley and 21 under potatoes. One small piece (4 acres) of old permanent grassland was ploughed up and cropped with barley.

Continuing with the policy of bringing all the non-experimental land at Woburn up to a pH of about 6·5, another 22 acres were given an application of ground chalk at rates varying between 1 and 3 tons/acre.

The usual classical wheat and barley plots were continued, as were the long-term rotation experiments. Two of these latter, the Green Manuring Experiment and the Irrigation Experiment, underwent a radical revision, and an account of the changes made is given elsewhere. The winter cabbage crop, which needs a lot of labour for planting out and cutting, was eliminated from each of these experiments, and this considerably eased the pressure of work.

The programme of experimental field work was expanded this year to include a short-term experiment on winter wheat. There can be very little further expansion of cereal experiments at Woburn because of the difficulty in handling any more plots at harvest-time, unless the new technique involving the use of the combine-harvester is adopted. It is hoped that a self-propelled combine, which can be shared between the Rothamsted and Woburn farms, can be bought for the 1955 harvest. A considerable increase in the number of cereal plots will then be possible. This year the plots were threshed by the small drum, which was converted into a high-speed machine for this purpose. The main advantage of having this machine permanently at Woburn is that the work can be spread over a longer time and can be done when outside work is not possible.

Weather during the autumn of 1953 and most of January 1954 was very favourable to farm work. This mild, dry spell enabled the

field work to be carried on without interruption, and by the time the hard weather set in at the end of January, field work was almost completed. The mild autumn induced a large number of weed seeds to germinate, and the small areas of winter wheat were more weedy than usual. On several areas scheduled for spring crops, two and three ploughings were done to destroy these weeds. During this fine spell the opportunity was taken to get the farmyard manure applied and ploughed in for the 1954 potato crops.

The preparation of seedbeds for spring-sown crops started in the second week of March, and the corn drilling was completed before the end of the month. April was very dry, the total rainfall being less than $\frac{1}{4}$ inch, and the planting of potatoes and the drilling of sugar beet was completed by the middle of the month; the various grasses and clovers were also sown under good conditions during this dry spell, which lasted into early May, and most of the corn crops were sprayed with DNOC or MCPA. Germination and growth of all crops, including grass, were retarded by this cold, dry spell.

During each of the four summer months, May to August, the rainfall was well above the average, and was spread over most days of each month; there were about 50 hours less sunshine in each month, and the mean temperature was several degrees below normal. These conditions, besides making the hay harvest extremely long and tedious, made the control of weeds more difficult, encouraged the spread of disease and retarded the ripening of the crops.

The cereal crops, most of which were spring sown, generally looked promising throughout the summer. Despite the heavy rainfall and fairly generous applications of nitrogenous fertilizers, the Herta and Proctor barleys remained upright, as did the Atle wheat. Serious lodging occurred only on some of the experimental plots. Bird damage was greatly reduced this year, and the only serious loss was a 2-acre piece of non-experimental winter barley, which ripened long before any of the other crops.

Harvest operations started in the third week of August, about 3 weeks later than usual, and, though somewhat protracted by unsettled weather, were finished 4 weeks later. The work was facilitated by the fact that very little lodging occurred. All the cutting was done by binder, and most of the corn was stacked in Dutch barns at the farmstead.

The permanent wheat and barley plots were very weedy, and crop growth was seriously affected. On some of the plots only small areas could be harvested. The wheat area was sprayed with both DNOC and MCPA, and not only was twitch (*Holcus mollis*) unaffected, but knawel (*Scleranthus annuus*) and sheep's sorrel (*Rumex acetosella*) seemed to suffer only a temporary check. It has been decided to fallow this area in 1955. In an attempt to reduce the twitch (*Agrostis gigantea*) on the permanent barley area the land was ridged during the winter, and then the elevator potato digger was used to separate the rhizomes from the soil. They were then forked up and carted off. Although a lot of the weed was removed by this method, much remained, and of course spurrey (*Spergula arvensis*) was present in large quantities, as usual. No herbicides were used, but despite the very weedy state of the area, it has been decided to crop it again in 1955, after an application of ground chalk to bring up the pH to about 6·0.

After a slow start the maincrop potatoes maintained satisfactory growth during the summer, despite the lack of sun. The variety Majestic was grown on all experimental areas and some non-experimental ground, but King Edward VII was grown again on 6 acres after an interval of many years. As weather conditions were very conducive to Late Blight, all areas were sprayed three times with a copper fungicide, and the King Edwards were given an additional early spraying. Yields of both varieties were satisfactory, and the tubers were less affected than usual by scab. Weather conditions were reasonably kind for lifting, which started within a few days of the completion of the corn harvest and lasted nearly three weeks. The crop was stored under cover at the farmstead.

The small area of sugar beet was the most disappointing crop of the year. It was drilled at the end of March and early April, and so felt the full impact of the drought during April. Germination was very slow and uneven, and some plants had reached the singling stage while others were just appearing above ground. Subsequent growth was slow, and the plants suffered a further setback from a severe attack by the mangold fly (*Pegomyia betae*), against which spraying had to be done. Crop yields were low, as was the sugar content.

By the end of October the harvesting of the root crops was completed, and all except one of the small areas of experimental winter corn were drilled. However, before much autumn ploughing could be done the weather broke, and in November over 4 inches of rain were spread over 23 days. Dung carting and ploughing went on intermittently during November and early December, but a fine, dry spell just before Christmas gave considerable impetus to this work.

There is still quite a lot of winter ploughing to be done, mainly on the heavier fields, and this work has seldom been so far behind schedule as this year. One of the heavy fields which was waterlogged for many years was mole drained in the autumn into tiled main drains.

The grassland greatly benefited from the wet summer and, after a late start due to the April drought, maintained good growth throughout the season. The usual burning up on the light land in July and August did not occur. The new ley undersown in 1953 was very productive and, after a heavy hay crop, provided a lot of aftermath. In fact, extra cattle had to be bought to graze it. There was a good bulk of hay, but weather conditions delayed cutting until the latter half of June, by which time the grasses were at a rather forward stage of growth. The cold, wet weather made haymaking a difficult operation, and though no hay was first class, none was spoilt. Some of the hay aftermath showed signs of acute nitrogen deficiency, despite a top dressing of 2 cwt./acre "Nitro-Chalk".

Livestock

Cattle

The cattle policy at Woburn consists of buying in young store cattle in the autumn, overwintering them in yards to make farmyard manure, and fattening them from the grass during the summer and

autumn. Devon cattle were bought in the autumn of 1953, and after the yard had been filled early in 1954, the remainder were outwintered. They were sold fat during the summer, and a small bunch of forward Hereford-cross cattle were bought in the early autumn to finish off on the plentiful supply of grass.

Pigs

The Large White pig herd was maintained at ten breeding sows, which are replaced as necessary by gilts of our own breeding. Most of the pigs were run on to bacon weights, only those making small liveweight gains being sold at an earlier stage. Grading results were reasonably satisfactory; of 135 pigs sent to the bacon factory 66 per cent were in grade A and 25 per cent in grade B.

WOBURN EXPERIMENTAL STATION

H. H. Mann

Season

The year 1954 will be remembered as one of the most unusual that Woburn has had, in that it was, for almost all the season, cold, wet and with an unusual absence of sunshine. In fact, every month from May to September had rainfall above the average, was less sunny than expected (except September), while the maximum temperature was below the average by 2–3 degrees every month. This has meant that all agricultural operations have been late, that certain crops, like sugar beet, have been far below expectation, and that, even on a light-land farm, the year can only be classed as a very poor one. The meteorological records from October 1953 to the end of 1954 are shown below.

Meteorological Records for 1953–54

Month	Rainfall: Total fall, inches	Rainfall: No. of rainy days	Bright sunshine, hours	Temperature: Max., °F.	Temperature: Min., °F.	Temperature: 1 ft. in ground, °F.	Grass min., °F.
1953							
October ..	2·13	13	68·4	55·8	42·3	51·1	37·4
November ..	1·31	10	55·2	50·9	42·0	46·1	37·3
December ..	0·58	13	32·2	47·9	39·9	45·0	30·4
1954							
January ..	0·91	9	62·4	40·9	31·2	37·6	27·0
February ..	2·22	17	68·5	41·6	30·3	35·9	25·6
March ..	2·38	13	100·6	48·6	35·4	41·3	32·1
April ..	0·23	7	174·8	53·9	34·4	46·8	28·3
May ..	2·61	16	132·5	60·3	43·4	52·7	39·1
June ..	3·03	17	132·4	63·6	49·2	58·6	45·1
July ..	2·47	20	135·4	65·1	51·1	60·2	45·5
August ..	3·50	20	119·6	65·9	51·2	59·2	46·9
September ..	1·99	20	166·1	63·2	47·8	56·3	43·2
October ..	2·28	21	99·6	59·3	47·6	52·8	43·6
November ..	4·17	23	55·3	50·3	37·6	44·6	32·5
December ..	2·24	15	61·4	48·1	42·4	41·6	33·5
Total or mean for 1954 ..	28·03	198	1,308·6	55·1	41·8	49·0	36·9

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them that may be recorded here.

Continuous wheat and barley

There is no doubt that there has been a general tendency for the crops of wheat and barley to fall off in the experiments where no other crop than wheat or barley respectively have been grown since

1877. This has been traced, at least in part, to the tendency of the land to become acid, especially where the soil was poor in lime from the beginning. The result has been, in the case of barley, an increasing failure of the crop, or, where it did not entirely fail, a remarkable stunting of what survived. With wheat, though the tendency has been similar, the reduction in yield has not gone so far and it has been possible to get reasonable crops, though far less than was obtained in the early days of the experiment. The difficulty of the increasing acidity of the land is not, however, the only factor in causing the reduction in yield. There is also the great difficulty in keeping down weeds. Perennial grass weeds, such as *Holcus mollis* and *Agrostis gigantea*, can only be kept in check by frequent fallowing, and the same method has been used in getting rid of serious infestations of wild oats. As far as annual weeds are concerned, most of these can now be checked by chemicals such as dinitro-ortho-cresol (DNOC) or by hormone weed killers. The chief weeds, however, in this area, namely spurrey and chickweed, are little affected by either type of weed killer, though others, such as mayweed, have been almost completely eliminated.

There is a third possible factor in the steady reduction of yield in these areas, particularly with barley : namely the possibility that the continuous growth of any crop, even of the cereals and particularly on light soils, may have made the land unsuitable for the further growth of the same crop. This happens quite soon with certain crops, notably with clover or lucerne, but has not been noticed with cereals. If this occurs, it is much more likely to be found in the lime-deficient, sandy loam at Woburn than in other areas.

On the whole, therefore, it has been decided to lime the whole of the continuous wheat and barley areas to a pH value of about 6·0, and then, possibly, to study the effect of weeds on part of each plot. The investigation of these points will greatly increase the value of the wheat and barley plots at Woburn in future.

Green manuring experiment

The scheme of this experiment, which was started in 1936, was changed in the present year, and details of these changes will be found elsewhere. The combined results of the experiment will shortly be published, but there are one or two points of immediate interest. These deal with the question of the importance of organic matter in the soil in increasing the crops which follow its application. The general result of many years of experiment seems to be that the crop-producing power of organic materials used as manures depends, in the main, on two factors, namely the length of time they have been in contact with the soil before the plant makes use of them, and on the percentage of nitrogen which they contain on a dry basis. With materials containing a large percentage of nitrogen, the maximum effect is obtained after very short contact with the soil, and the efficiency falls off substantially when the interval before they can be utilized increased. The time of contact which gives maximum efficiency increases as the nitrogen in the manurial material decreases.

Effect of irrigation on a new grass ley

In the irrigation experiment started at Woburn in 1951 under the general supervision of H. L. Penman, a new area of grass was laid

down in 1954, with pure cocksfoot grass. Little or no effect of irrigation on the yield of grass this year was shown, on account of the wetness of the summer, but in the autumn it was possible to estimate how far the cocksfoot grass had remained pure and how far the all but worthless *Poa annua* (which is of universal occurrence) had come in to replace it. The actual determinations were made by D. J. Watson and showed that the addition of irrigation water seemed to have doubled the percentage of this worthless grass. How far this is the result of the wet season, and possibly of the presence of an excess of water in the highly irrigated soil, is not yet known, but it is hoped to repeat the tests in the middle of 1955.

New Crops

The exceptionally wet, sunless and cold summer has enabled us to observe how rather delicate crops like maize behaved under these conditions, and in that sense 1954 has been a very useful season.

Maize

We have now several early-ripening hybrid varieties of maize from Wisconsin and also from Holland which have given very good results in the last 4 or 5 years when the seasons were more normal, so that their behaviour in 1954 was of particular importance. Apart from the usual trouble with rooks in the early stages (where we have found that the plants are not really safe until they are at least 6 inches high), it seemed, up to the middle of August, as if the the summer would be too cold for maize and that the crops would never ripen. From this time, however, the maize plants seemed to recover tone and ultimately ripened a month late, so that it was possible to harvest practically ripe ears from 25 October to the middle of November. At this time of year the grain would not be much use, except for immediate consumption by pigs or chickens, without a corn drier, but, when dried, the yield of grain was very satisfactory. Wisconsin 240, the variety which has given the most consistently good results, gave an average yield of dried grain (for a full plant) of 36 cwt. of grain per acre when sown on 23 April, 33 cwt. when sown on 4 May and 23 cwt. when sown on 12 May. Even better results were obtained with a Dutch variety (Goudster), which gave over 40 cwt. of dried grain per acre from seed sown on 4 May, when calculated for a full area without rook damage.

Fodder crops for semi-acid soils

(1) *Jerusalem artichokes.* Perhaps the most interesting work in this connection in 1954 has been the testing, for the first time, of a specially luxuriant strain which has been developed in Germany in recent years and is now on the market under the name "*topine*". This has been developed, so far as the parts above ground are concerned, chiefly for silage making, the tubers being used for pig feeding in the following spring. This strain was sown on 26 April in a soil prepared and manured as for potatoes, the tubers being planted in rows 2 feet apart and 8 inches between the tubers in the rows. They grew well and steadily, reaching a height of 8–9 feet by the middle of October, and forming an almost impenetrable mass of vegetation. The crop was cut on 20 October at 12 inches above the ground, and gave a yield of green stuff and stalks of from 17 to 18½

tons/acre. The dry-matter content of this varied from 18·4 to 21·3 per cent, and the crude fibre content (on the dry matter) was 31·0 per cent. There are at Woburn no facilities for making silage experimentally, but some of the material was given to store cattle in the field. They ate the leafy part greedily, but would hardly touch the stalks. On the other hand, both leafy parts and stalks were eaten keenly by pigs. The proportion of leaves to whole produce was about 35 per cent. The dry matter of the green stuff had a nitrogen content of 1·67 per cent, equal to a crude protein figure of 10·4 per cent. The tubers cannot be pitted like potatoes, but are left in the ground until February, when they can be dug and used for pig feeding. The yield of tubers will be at least 8 tons/acre, but the exact figure will be ascertained at lifting time. The crop, in the specially luxuriant "topine" strain, seems promising, and should receive more widespread tests in 1955.

(2) *Sweet Lupins.* Experiments carried out for several years showed that sweet lupins might be a very valuable addition to our fodder resources on semi-acid land; but the crops of 1953 showed such a large amount of inedible stalk that an attempt was made in 1954 to see whether a more edible material could be obtained by growing the crop later in the season and reaping it at an earlier stage of growth. Two varieties, Neven and Weiko, were sown on 29 June, and in spite of the chilly weather, they both grew well, though not so luxuriantly as in warmer years. When cut in full flower on 13 October, the two varieties gave yields as follows:

Variety	Yield of green fodder per acre, tons	Dry matter, %	Dry matter per acre, tons	Edible, %
Weiko ..	16·1	9·6	1·55	72·2
Neven ..	13·9	10·1	1·40	83·3

Thus, by sowing late, i.e., at the end of June, there has been produced a much smaller total crop of green stuff, but the percentage of edible matter has been very much increased. The nitrogen content of the dry matter was, respectively for the two varieties, 4·26 and 3·69 per cent, equal to 26·6 and 23·1 per cent of crude protein. This amount of valuable feeding matter was obtained in an unfavourable year 3½ months after sowing. There should be no difficulty in ensiling this material.

(3) *Serradella.* The growth of serradella was not so vigorous as in previous warmer seasons, and 1954 would seem to have reached the temperature limit for profitable growth.

The crop was sown on 7 May and had a bad start, but it grew very well from July onwards, and by 17 September gave 14·7 tons of green fodder per acre, containing 11·5 per cent dry matter. This represents a yield of 1·99 tons of hay per acre. We have thus a 5-year record of 2·14, 1·33, 2·84, 3·09, and 1·99 tons of excellent high-protein feed, or an average of 2·28 tons of hay equivalent per acre. The nitrogen in the dry fodder amounted to 2·78 per cent, equal to 17·8 per cent crude protein.

It seems clear that if seed is available, serradella is a reliable and excellent high-protein fodder. It should be sown at the beginning of May on well-drained, preferably light soil, which is in good heart, though not necessarily highly manured. Treated in this way it should become available early in September.

(4) *Birdsfoot trefoil.* This is a fodder which is supposed to be suitable for the class of land which is found at Woburn, and it will grow under conditions too poor for clover. It is perennial, but how long it will last and how far it will resist the competition of weeds and grasses after the first year is not known. The present small area was sown at the beginning of May 1952; it grew very slowly at first, and gave a moderate crop of clover at the end of September. The area was left for the third year, and again grew slowly in the spring, and the crop (especially the narrow-leafed variety) was rapidly becoming overgrown with grass. It came away ultimately, and was cut on 3 August. The actual yields were as follows:

Variety	Greed fodder per acre, tons	Dry matter, %	Hay equivalent per acre, tons	Crude protein in dry matter, %
Narrow leafed ..	7·25	18·2	1·55	14·7
Broad leafed ..	14·43	16·3	2·77	14·7

Laboratory Work

The year 1954 saw the completion of a study of the changes in the sulphur content of soils variously manured for continuous barley for a period of 50 years. This has now been written up and is in the press. The work makes it clear that under normal conditions the sulphur received from rain and other atmospheric sources is amply sufficient to maintain the sulphur content of the soil. This applies whether the soil is unmanured or has an application of ammonium salts, of nitrate of soda alone, or of superphosphate, potash or other mineral salts. During the 50 years when the application of fertilizers was made every year without any organic manures the carbon content of the soil was reduced and the amount of total and of organic sulphur was reduced almost to the same extent, but the humus sulphur was very much more steady. In free-draining soil, like that at Woburn, there is no evidence of a tendency of the sulphur to be carried down and remain in the subsoil within the range of barley roots.

Work in the pot-culture station and in the laboratory has been again restricted in 1954 by the demands of the irrigation experiments, and has hence been almost entirely concerned with what was necessary for the field experiments. Most of this work falls on T. W. Barnes and his staff, and they have been fully employed in these directions during the year.

TROPICAL SOILS

H. Greene

In August 1954 H. Greene led the United Kingdom delegation at the Second Inter-African Soils Conference, which was held in Léopoldville, Belgian Congo. The meeting was convened by the Commission for Technical Co-operation in Africa south of the Sahara, and was attended by over 100 scientists, including representatives of the signatory powers, Belgium, France, Portugal, the Federation of Rhodesia and Nyasaland, the Union of South Africa and the United Kingdom. Further progress was made towards implementing the recommendations of the earlier Conference (Goma, 1948). It is recognized that in the wisely concerted development of the African continent, soils and agriculture have an important place. Of the many technical papers, a good proportion was contributed by British delegates.

This inter-governmental conference was succeeded by the Fifth International Congress of Soil Science. Attended by nearly 200 scientists, this congress, held in the Belgian Congo, has probably made an important contribution to soil science in the tropics. H. Greene presented a paper entitled " Fertilizer prospects in Africa ". This stressed the possibilities of increasing agricultural production by application of major and minor plant nutrients : the pioneer work of Lawes and Gilbert and of Brenchley and Warington has not yet come to fruition in tropical agriculture.

During the latter half of 1954 H. Greene also visited the Gambia, Sierra Leone, Rhodesia, Nyasaland, Tanganyika, Kenya and, with the help of C. A. H. Hodge, did some field work in the protectorates of Aden and Somaliland.

In Nyasaland a visit was paid to Lake Shirwa, where projected cultivation of rice will involve irrigation with water of doubtful quality. Clay soil already affected by repeated contact with this water was found to be in a bad physical condition, so that prospects are not good. However, before abandoning the project it is intended to carry out some practical tests with rice, using very small plots irrigated with the suspect water.

In Western Aden Protectorate a successful irrigation scheme is threatened in some areas by waterlogging and consequent salinity. It seemed possible that the water is held up by a layer of impermeable clay which is exposed here and there in deeply eroded canals. Field tests of lateral permeability, made with equipment of special design, supported this view. The work continues, and it is hoped to ascertain whether the clay layer coincides with the present occurrence of waterlogging.

In Somaliland possibilities of irrigation in the Qabri Bahar area were investigated. This area is extremely difficult of access, is malarial and has no agricultural population. Inspection on the ground with aid from air photos gave no encouragement for early development : a false analogy had been drawn with the Abyan delta in Aden Protectorate. Elsewhere in British Somaliland there are interesting exposures of a major kind of soil not yet described.

It is hoped that C. A. H. Hodge will make a further study of this in a year's time.

When in England the Adviser on Tropical Soils is mainly engaged in receiving inquiries and reports from soil scientists overseas and in passing out to them news about books or techniques that seem likely to be of use. He has also to assist the Colonial Office in the recruitment and training of scientists for work overseas. The carrying out of these duties is much facilitated by the personal contacts that are possible at Rothamsted.

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

In spite of the exceptionally unseasonable weather for mapping, an additional 370 sq. miles have been surveyed, and field work on Sheets 75 (Preston), 95 (Rhyl), 107 (Denbigh) and 188 (Cambridge) is almost complete. Surveying is continuing on Sheets 238 (Aylesbury), 70 (Leeds) and 280 (Wells), and the last two sheets should be completed next year. New surveys have been started on Sheets 125 (Derby) and 166 (Church Stretton). This year has seen the publication of the map and memoir describing Sheet 138 (Wem), and the memoir to accompany Sheet 296 (Glastonbury) is in the press.

A. Muir visited Nigeria at the invitation of the Colonial Office to inspect the progress of soil survey work and afterwards attended the 2nd Inter-African Soil Conference and the 5th International Congress of Soil Science in the Belgian Congo, and visited some of the territories in Central and East Africa. After his return from Cyprus D. A. Osmond attended, at Ghent, the first meeting of a sub-group set up under the auspices of the Food and Agriculture Organization of the United Nations to study soil classification and survey in Europe.

During the year a Pool of Colonial Soil Surveyors has been started, the members of which are available for short-term soil surveys in places overseas where it is uneconomic to appoint a full-time surveyor; when not abroad, the staff participate in the soil surveys of Great Britain. Under this scheme A. O. Ballantyne has been sent to Northern Rhodesia, and C. A. H. Hodge (vice G. F. M. Murdoch) to Aden and the Somaliland Protectorate. L. F. Curtis has been sent to Iraq to carry out soil surveys in connection with irrigation schemes. R. D. Green spent a short time in the Netherlands studying methods of soil survey of land similar to that found in Romney Marsh.

Lancashire

Sheet 75 (Preston)

The survey of this sheet is complete except for a small part of the high moorland which has been too waterlogged for satisfactory mapping in this phenomenally wet season. The 20 sq. miles mapped on the 6 inches to 1 mile scale include a revision of about 10 sq. miles around Freckleton that had been mapped before the final classification had been established. The work has been mainly in the Longton and Freckleton districts, where till of Triassic material is frequently overlain by an alluvial deposit. The Salop, Cottam, Clifton and Salwick are the most widespread series on the boulder clay, but some variants occur as a result of the influence of the alluvium in the surface soil. On the alluvial deposits of the Ribble estuary the soils are very diverse owing to differences in texture and drainage.

Somerset

Sheet 280 (Wells)

Sixty-six sq. miles have been surveyed, including 32 sq. miles of the Mendip Hills, the northern extremity of the Wedmore ridge and the Winscombe–Banwell district.

The main interest in the Mendip Hills lies in the widespread occurrence of a fine sandy and silty superficial deposit, often accompanied by cherts, covering much of the Carboniferous and certain other formations, which normally gives rise to a brown earth soil. Where the rainfall is more than 40 inches a peaty gley soil with thin iron pan, the Priddy series, occurs on this deposit. Under similarly high rainfall, Lias Limestone gives rise to the Ston Easton series, which is more acid, lighter in texture and warmer in colour than the Somerton series developed on the same rock under drier conditions. A small area of Coal Measures sediments encountered in the east gave an introduction to soils that are more extensive in the north, but large areas covered by the remains of old surface workings necessitate the use of soil complexes as mapping units.

The soils of the northern portion of the Wedmore ridge were found to fall into previously established series, with the exception of a soil developed on thin Liassic shales and, while it is similar to the Evesham, it is much shallower and devoid of calcium carbonate; it was named the Ashton series.

The Winscombe–Banwell district presented a complex soil pattern due to the variety of geological formations exposed and the extent of Head and colluvial deposits on the slopes and in the valleys. A sandy deposit gives rise to the Tickenham series, in which about 24 inches of loamy sand or sandy loam overlie heavier material or gravel; as it frequently occurs on gentle slopes and is easily worked, it is an excellent soil for orchards, market gardens and nurseries. The Star series, a thin, loamy soil overlying a yellowish brown sandy facies of the Dolomitic Conglomerate, is also of interest in this district.

Shropshire

Sheet 166 (Church Stretton)

After a reconnaissance of the district had been made it was apparent that the complex distribution of the soils is largely the result of the considerable lithological variety of parent materials, although other factors are dominant at certain places. All geological formations from the Pre-Cambrian to the Carboniferous era are present; the Palaeozoic sediments are deposited against the Pre-Cambrian mass of the Longmynd, generally with a south-easterly dip. Glacial deposits which originated to the north and west of the region are more extensive than had been previously reported, but the Palaeozoic sediments are only partially obscured by them.

Of the 25 sq. miles mapped, selected areas were surveyed on the 6 inches to 1 mile scale to establish mapping units, the remainder being mapped at the scale of 2½ inches to 1 mile.

The parallel ridges of Silurian age, i.e., Wenlock Edge and the dissected ridge of the Ludlovian, that are aligned north-east to south-west, have been mapped from Easthope in the north-east to

Norton Camp in the south-west. A close correlation has been found between soils, parent material and relief, and there are four principal topographic units. On the south-east aspect of the Wenlock Limestone dip slope the main soil series is the Wilderhope developed on crystalline limestone interbedded with calcareous argillaceous deposits. The heavy-textured soil is a brown colour, freely drained and of variable depth, although normally limestone occurs within 3 feet of the surface.

In Hopedale, a strike valley in the Lower Ludlow Shales, the Stanway and Speller series are slightly gleyed and gleyed soils respectively. Medium to heavy in texture, they are mainly sedentary, but occasionally are influenced by colluvium.

On the south-east aspect of the Upper Ludlow Shales dip slope the Munslow series consists of brown to yellow-brown, silty or fine sandy light to medium loam. Shallow soils develop also on the Upper Ludlow Shales and some thin limestone bands.

The soils on the north-west aspect of the Ludlow Shales are more varied. The steep phase of the Munslow series is an immature, yellow-brown soil of light texture occurring on the steep upper slopes of the escarpment, which are subject to erosion. In the depositional zone the Yeld series is partly developed on colluvium. Together with the Stanway and Speller series it forms an association.

Approximately 4 sq. miles were mapped on the 6 inches to 1 mile scale in Corvedale on the basement beds of the Downtonian, the younger Ledbury red marls and alluvium of the Corve. Soils similar to the Eardiston and Bromyard series were identified, but the soil pattern is so confused owing to the repetition of thin marl and sandstone bands that the soils have mainly been mapped in an as yet unnamed complex in which the Bromyard series is the dominant member.

Yorkshire

Sheet 70 (Leeds)

Surveying has continued on the scale of 6 inches to 1 mile, and about 50 sq. miles, including some revision, have been mapped. Work started near the northern boundary at Bilton in the hummocky country at the western end of the York and Eskrick moraines overlying Triassic rocks. Soils of light and medium texture predominate on the higher ground with clay or silty soils, both in the depressions notably occurring east of Wetherby and in the slightly lower country about Catterton, north-east of Tadcaster.

To the west, the junction with the Permian limestone occurs near Wetherby, where the soil pattern is complicated by the Kirk Deighton glacial overflow channel with its associated gravels and alluvial soils. About 1 mile west of Kirk Deighton is the junction of the Permian and Carboniferous formations, but most of the country is covered with heavy till mainly derived from the shales of the Millstone Grit. In the extreme north-west at Rigton High Moor (about 700 feet O.D.), moorland variants of impeded soils on heavy-textured Carboniferous drifts have been mapped. Notwithstanding the greater altitude, sharper relief and unpromising parent materials compared with most of the area, the land is moderately productive if well managed, and carries a heavy stock of sheep and dairy cattle

on the better farms, where lime and phosphatic manures are plentifully used.

On the western edge of the sheet the Wharfe valley is crossed by the Arthington moraine, below which some of the best arable soils in the district are found on the fluvio-glacial terraces. Mainly arable crops are also grown on the alluvium, which generally has a fine sandy to silty loam texture and is freely drained, though liable to occasional floods even in summer. The southern face of the Wharfe valley is generally moderately steep between Pool and Harewood, and the interbedded sandstones and shales produce a complicated soil pattern.

From the Wharfe valley to the suburbs of Leeds, heavy-textured till of Carboniferous origin gives soils with impeded drainage, broken by outcrops mainly of coarse-textured sandstone on higher ground, and in the Bramhope district these gritstones produce podzolized soils. Most of the Aire valley on the sheet has been built over, but where this has not happened, and especially outside the western edge of the sheet, the alluvium is intensively used for market-garden crops and rhubarb growing.

Hertfordshire and Buckinghamshire

Sheet 238 (Aylesbury)

A further 57 sq. miles have been surveyed, and a little more than half of the sheet has now been completed. On the Chiltern plateau the survey was continued in the south-west around the Hampdens, Great Missenden and Lee, and in the north-west around Redbourn, Flamstead and Markyate. In general, the soil pattern conformed to that described in previous reports, although in the latter district the more gentle relief modifies the distribution of the soils; the Batcombe series being less extensive on the level tops, and correspondingly the Winchester series is more widespread. In the Ver valley around Redbourn there is an extensive stretch of valley gravel which may be water-sorted and, in places, appears to be covered by as much as 18 inches of relatively stoneless loam. Somewhat similar soil has been observed overlying the Head deposits in the Tring and Wendover gaps, and provisionally grouped as a variant of the Charity series. Slightly higher up the valley sides near Redbourn and on the western sides of Harpenden dry valley near Luton Hoo, some very gravelly soils have been grouped with the Berkhamsted series.

In the Vale of Aylesbury, work was continued between Wiltstone and Wingrave, where a new series has been named after the latter village. The soil is formed on the glacial gravels capping the 400-foot ridge running west from Mentmore, and consists of a brown, gravelly, sandy clay loam, 2–4 feet thick, overlying Gault clay. A poorly drained variant of the Gubblecote series has been named the Wiltstone series.

Cambridgeshire

Sheet 188 (Cambridge)

Mapping continued in the south-west and north-west of the sheet, where 31 sq. miles were surveyed; no new series were required, and the sheet is practically complete. The south-west district

includes the city, and is divided into two parts by the Cam. The eastern part, reaching to Cherry Hinton, Horningsea and Quy Water Bridge consists of a low ridge about 25–30 feet O.D. of Chalk Marl with soils of the Wantage and Burwell series, and large stretches of the Swaffham Prior series, where traces of drift are present. The Lode series, developed on the Cambridge Greensand, forms a narrow band crossing from north-east to south-west. Small patches of Gault occur, and in the river valley the soils are of the Cam series. The western part, as far as Coton and Girton, lies between 30 and 90 feet O.D., and consists mainly of Gault, on which the Peacock and Wicken series are developed, while on sands and gravels the Landbeach and Milton series are found. Madingley Hill (200 feet O.D.) consists of Chalk Marl capped by Boulder Clay, the latter giving rise to the Stretham series. The Lode series again occurs at the foot of the hill.

The north-west district, mainly north of the Old West River and between Haddenham and Earith, consists of Fenland from which the Haddenham ridge rises to over 100 feet O.D. In the Fenland the soils range from peat to sandy clay loam with patches of the Clayhythe series. Part of the area, especially in the north-west corner and along the Old West River, is occupied by the Cam series, which is generally non-calcareous except where shell marl occurs as in Willingham Mere. At the foot of the Haddenham ridge, Kimmeridge Clay appears on which Wicken and Peacock soils are developed. At the junction of the clay and the Lower Greensand, soils of the Oakington series are found and, higher up the slope, the latter formation gives rise to the Cottenham series. On the summit of the ridge the Stretham series is found on the capping of Boulder Clay.

Denbighshire

Sheet 95 (Rhyl) and 107 (Denbigh)

The mapping of a further 98 sq. miles that includes the greater part of the Vale of Clwyd completed the survey of these two sheets. In the main the soils are developed on parent materials described in previous reports with the addition of chert beds of the highest beds of the Carboniferous Limestone, sandstones of the Millstone Grit formation and small outcrops of Triassic sandstone. The first two mentioned give rise to loams and sandy loams in the districts around Gronant and Llanasa. Soils of the Triassic sandstones contain variable amounts of material from the Silurian shale, but generally not in sufficiently high qualities to warrant the establishment of a new series, and they have been mapped with the Newport series. Only in two small areas near Llanrhiadr are there any soils formed directly on the sandstone.

Extensive areas of river alluvium were mapped between Llanrhiadr and Bodfari, where soils of four drainage categories were recognized and separated. Peat is formed locally in the wettest areas. On much of the ground bordering the alluvium, especially near Denbigh, the soils of the Penrhyn series tend to be gravelly. The gravels are probably outwash deposits from an ice-front, and are composed entirely of shale material. Morainic mounds of mixed shale and Northern Boulder Clay occur near Newmarket. The soils

on the crests of features resemble the Eriviat series, but are distinguished on the basis of their mixed origin.

On the eastern side of the Clwyd river between Bodfari and Tremeichion, and to the west between Green and Trefnant, soils of the Aber series merge almost imperceptibly into a deep phase of the Cottam series. Although the soils of the latter closely resemble those of the Aber series in texture, they have only a small amount of shale in the surface soil. To establish satisfactory boundaries it was necessary to examine a number of selected surface soil samples and determine the approximate amounts of shale material present.

Other Work

Following a request from the Agricultural Improvement Council, work has started on a detailed soil survey of Romney Marsh, and about 3,000 acres have been examined. The soil pattern is exceedingly complex, and is related to the nature and mode of deposition of the alluvial deposits composing the Marsh, the micro-relief and the drainage conditions. It is considered that the nine series established during an earlier survey by L. W. Cole and J. K. Dubey of Wye College, with some additions and modifications, will provide a satisfactory basis for classifying the soils in many parts of the Marsh. For mapping purposes, it will probably be necessary to group two or more series into defined complexes, the distribution of which will frequently be related to micro-relief and the mode of deposition.

At the request of the Ministry of Agriculture a survey of some 15 sq. miles was made of the Sussex coastal plain between the rivers Arun and Adur. Only two new soil series were described, the others had already been established by earlier work of the Survey and by Dr. F. F. Kay during a survey of the strawberry-growing area in Hampshire.

In Devon, a large farm was surveyed belonging to the Devon School of Agriculture on which the soils are derived from Triassic sandstones and alluvial deposits of differing ages. In Somerset, an experimental husbandry farm was surveyed for the Ministry of Agriculture. Soils of established series developed on Devonian shales were recognized.

The Agricultural Land Service requested a survey to be made of relic mosses in Lancashire. A report was prepared describing their general character and their agricultural potentialities, together with detailed accounts of Holiday and Holker Mosses.

A reconnaissance was made of soils in opencast ironstone mining areas as a basis for further study of some of the problems of soil restoration, and investigations are proceeding on the variation of the weathering rates of different kinds of limestone, since these appear to differ considerably, and locally constitute the major part of the restored material.

Some 4,000 acres were surveyed in detail in the Vale of Belvoir with a view to the production of a reconnaissance survey map. Several established soil series were recognized on the clays and limestones of the Rhaetic, Lower and Middle Lias formations.

A survey of some thirty farms has not shown any correlation between incidence of Johne's disease in cattle and soil series or

conditions present in the pastures. Analysis of pasture samples for fifteen major and minor elements has given no indication that incidence of clinical cases can be correlated with an abnormality in mineral nutrition derived from the pasture. Milk fever, which is a failure of calcium-magnesium metabolism, is commonly reported in these herds.

This survey has again confirmed that the disease assumes very serious proportions in many apparently well-managed herds, Channel Island herds showing a high incidence of clinical breakdowns. Considerable difficulty is experienced in obtaining true incidence data, because in the absence of an acceptable diagnostic test the disease has not yet been made notifiable.

Analytical work on soils associated with several archaeologically interesting sites has been carried out. These included the Piltdown Skull site and also a round barrow, where an interesting deposition of MnO_2 inside the silted up coffin was still quite obvious. This deposition had apparently been caused by the presence of the decomposing organic matter.

CLAY MINERALS

By

G. Brown & R. Greene-Kelly

Introduction

Fundamental studies on the mineralogy of the clay fraction in soils were initiated in the Chemistry Department at Rothamsted shortly before the war. With the outbreak of war the work largely ceased, and it was not resumed until A. Muir came in 1945 from the Macaulay Institute for Soil Research to start the Pedology Department. The work carried on since the war falls naturally into two parts, which will be considered separately. The first is the study of mineralogy of clays * and the second the study of their properties.

Mineralogy of Clays

Introduction

To define a mineral we must know its composition and either its structure or some properties which are related to its structure. The vast body of mineralogy was built up before methods of determining structure existed, and such properties as refractive indices, birefringence, shape of crystals and hardness were used to define structural types. With minerals which form visible crystals there is no difficulty in finding their composition, for almost pure samples can be separated. With the clay minerals, which for the most part exist as crystals less than 1 μ in diameter, isolation of pure materials is not easy, and the structural properties which can be obtained with light microscopes were often determined on impure materials.

With the advent of X-ray diffraction a direct method of determining atomic arrangement in crystals, that is their structure, became available, and has been applied with success to a large number of mineral structures. The information obtained from X-ray-diffraction spectra is of two kinds; the geometrical distribution of reflections is a measure of the geometry of atomic planes in the crystal, in particular their interplanar spacings and interplanar angles; the intensities of the reflections are related to the arrangement of atoms in the planes. With a single-crystal specimen, spacings, angles and intensities can be measured. With fine-grained materials such as clays we cannot obtain single crystals large enough to handle, and powder specimens, which are really aggregates of more or less randomly oriented small crystals, must be used. From patterns obtained with powders we can, in theory, obtain interplanar spacings and intensities of reflections; but we can derive little information from them about interplanar angles, and hence complete structure determinations are not possible except with the simplest structures. With complex structures the reflections from different sets of planes overlap, so that the information obtainable

* For a recent review of this subject see G. W. Brindley (1951). *X-ray identification and crystal structures of clay minerals.* (London: Mineralogical Society.)

from powder patterns is limited. However, structure determinations on minerals such as micas which are similar to the clay minerals, but which form larger crystals, led to a realization of the principles which appear to govern the structures of such materials. Information on the co-ordination of cations and what kind of isomorphous substitutions could occur became available, and by comparing X-ray powder patterns of well-crystallized layer silicates with those of clays, the broad outlines of the structures of the different groups of clay minerals have been obtained.

Knowledge of the structures of clay minerals gives a method of determining the purity of a clay mineral sample by comparing the observed X-ray-diffraction pattern with that expected from a particular structure. In this way, from information on the chemical composition and X-ray patterns of apparently mono-mineralic clays, a body of knowledge has been built up which enables the different clay mineral groups which are present in a mixture to be recognized.

The majority of clay minerals have layer structures consisting of parallel layers containing Si, Al, O and OH and sometimes Mg, Fe and other elements. The layers consist of parallel sheets of atoms which are firmly bound together so that the layers are fairly stable; between layers the forces are usually weaker. Thus sheets of atoms are bound together to form layers, and layers are superposed to form crystals. The classification of the clay minerals is largely based on structural considerations, for the compositional range within groups is of the same order as between groups.

In the structural field there are essentially two main types of layer which form clay mineral crystals. First, there is the type of layer found in minerals of the kaolin group, which is often called a 1 : 1 layer, as it is made up by the condensation of one sheet of tetrahedrally co-ordinated cations with one sheet of octahedrally co-ordinated cations. The thickness or height of a single 1 : 1 layer is about 7·2 Å. The other type of layer, which is the basic layer of micas, chlorites, vermiculites and the montmorillonite minerals, is the 2 : 1 type, for it is made up by the condensation of two tetrahedrally co-ordinated sheets of cations, one on either side of an octahedrally co-ordinated sheet. The thickness of a single 2 : 1 layer is about 9·3 Å. In a broad way we cay say that 1 : 1 type layers are electrically neutral in themselves. The 2 : 1 layers often carry a negative charge due to isomorphous substitutions, and these negative charges are balanced by positively charged atoms or groups of atoms which are intercalated between successive 2 : 1 layers. This leads to the range of minerals made up of 2 : 1 layers, for both the size of the negative charge per unit volume of layer and also the nature of the balancing positive group can change. Thus the layer height for the minerals composed of 2 : 1 layers depends on the size of the positively charged interlayer group. In the micas K^+ ions balance the charge on the 2 : 1 layers and the thickness of a mica layer is about 10 Å., in the vermiculites moderately hydrated cations are found between the 2 : 1 layers and the height of a vermiculite layer is about 14 Å., and in the montmorillonite minerals the balancing cations are even more highly hydrated and the layer height depends on the precise nature of the cation and the humidity. It is chiefly on the basis of these different layer thicknesses that the clay minerals in mixtures are recognized by X-ray methods; the X-ray-

diffraction pattern, since it measures the distance between similar planes of atoms, gives a direct measure of the height of the layers.

Soil clays

The work of this department in connection with soil clays can be divided into three parts. First and most important, for all else depends on it, has been the improvement of methods of obtaining X-ray-diffraction patterns, then development of methods of interpreting some of the complex diffraction patterns obtained and finally investigation of the best ways of applying these methods to the study of soil genesis.

The chief method used to identify soil clays is by X-ray-diffraction patterns, and until recently it was frequently suggested that amorphous material, including organic matter, in soil clays interfered with the diffraction patterns. Various chemical methods have been used to remove the amorphous inorganic material by solution, and organic matter by oxidation and solution. In some cases it appears that the composition of the crystalline clay fraction is altered by these treatments. In the work in this department on soil clays from many different parts of the world, we have found that the cleaning of clays is not necessary in order to obtain good, clear diffraction patterns. The reflections may not always be sharp; but in such cases the broad reflections are due to the nature of the material, which is often imperfectly crystallized. It appears that the use of cleaning techniques arose out of poor X-ray technique and that if proper attention is given to features such as clean radiation and good collimation, diffraction patterns with clear reflections will generally be obtained. This must not be taken as a suggestion that " amorphous " matter does not exist in soils or even that it is rare; but when it is present it is better to examine the specimen before treatments are applied to remove the poorly crystallized fraction. It would seem desirable to disperse soil clays using the mildest possible reagent, and then the results apply more directly to clays as they exist in the field. Having examined the clay as it is in the soil, we can apply cleaning treatments and relate their effects to what was present in the untreated clays.

Examination of soil clays from England, using mild dispersion treatments, has shown the presence of the hydrated iron oxide, lepidocrocite, in many soils which show the orange mottling characteristic of impeded drainage. Had the clays been treated to remove amorphous matter, the form of the iron oxide would have been left unknown, and it is suspected that failure to detect lepidocrocite earlier and more frequently is due to treatments to " purify " the clay minerals.

In connection with the interpretation of X-ray-diffraction patterns of clays, work has been done on interstratified clay minerals. It was pointed out in the introduction that slight variations in the interlayer grouping have different layer heights characteristic of different minerals. Usually, individual crystallites are composed of only one type of layer of a characteristic thickness, and a sample may be composed of a mechanical mixture of two kinds of crystallites, one with say 10 Å. layers, i.e., mica, and another with 14 Å. layers, i.e., vermiculite. However, in some cases within a single crystallite both 10 Å. and 14 Å. layers occur. These layers may be

arranged in a regular way with respect to each other, or they may be randomly distributed within the crystallite, and the interpretation of the diffraction effects from randomly interstratified systems has formed part of our work. The first step was to apply the formulae developed by Hendricks and Teller to the calculation of the patterns which would be given by a number of two-component systems which were likely to occur in soil clays. This involves several rather tedious calculations for each system, since different patterns are given by different proportions of the two components. X-ray patterns of randomly interstratified minerals are then interpreted on the basis of the best fit between the observed and calculated patterns. A detailed study has been made of an artificially prepared randomly interstratified two-component system in which some control over the proportions of each component could be exercised. The good agreement obtained between calculated and observed patterns of a range of proportions showed that the theoretical treatment was essentially correct. All the above required laborious calculations, and more recently a modified Fourier transform method has been proposed which gives the types of layer present, their proportions and their relative distributions. It also has the advantage that it can be used for systems with more than two components, although in such cases ordinary transform methods would be preferable. The transform method has been applied with success to montmorillonite–water systems.

Having established methods for taking and interpreting X-ray-diffraction patterns of clays, one of the questions arising is how best to apply our methods to the study of soil genesis. In the mineralogical field we are interested in how minerals in the soil parent material alter to give other minerals under the soil-forming processes; in particular, how rock minerals alter to clay minerals and how one clay mineral alters into another. Apart from the fact that the products of weathering form the major part of the soil, the way in which minerals break down influences the composition of the soil solution from which plants extract their nutrients.

In the past, alteration studies of clay minerals in soils have usually been made over a wide geographical range or on soils with well-developed horizons or a combination of both. The wider the spacial range covered by the study and the longer time interval from the beginning of the alteration, the greater the number of variable soil-forming factors and the greater the variation in individual factors. The results obtained from such studies can only give a time-average of all the processes which have been effective. It is obvious that soil profiles do not form initially in horizons; in fact, soil horizons are an idealization. It is rare for a soil horizon to appear homogeneous even to the unaided eye, and alteration processes occur on an infinitely more minute scale. When the soil-forming processes act on the parent material the reactions begin at points of weakness in the parent material and initial alteration is localized around such points. If there are several processes operating with different rates, we may be able to find zones with different degrees or types of alteration around active centres, and ideally we should be able to obtain information about the many processes which contribute to the end-product.

To approach the ideal of studying a single reaction, an effort is

being made to study alteration in and around small areas in the soil matrix where differences are visible. This method has several other advantages; it employs more fully the X-ray technique, which only requires small samples, it makes use of natural concentrations and so allows ready detection of minerals which are present in small amounts in the total soil and which can easily be overlooked in bulk-horizon samples. In addition, readily visible morphological features are among the criteria on which soils are classified in the field, and the information obtained will apply directly to such features. It is hoped that such studies will throw light on incipient changes and intermediate alteration stages, for the time required to develop a small feature is greatly less than that required to form an horizon, and the distance between reacted and unreacted material is small, so that constant parent material can more justly be assumed.

A preliminary study of some poorly-drained soils from Lancashire somewhat along these lines has affirmed the evidence of an earlier, broader study that lepidocrocite is an important pigment in the orange-coloured mottles associated with impeded drainage. In addition, the study showed that in these soils the clay mineral in the soil matrix in which the mottles are found were, as far as could be detected, similar in kind and amount to the clay minerals in the mottles. This evidence suggests that the iron moved into the mottled area from wherever it was released by iron-bearing minerals; for if the iron oxide in the mottles had been due to local concentrations of iron-bearing minerals in the parent material, then their alteration products would be expected to have some effect on the clay-mineral composition of the mottles.

The broader studies on a horizon basis are valuable, but for information about a particular reaction we need to use more detailed methods, for the results of broader studies are intractable to anything but a general analysis in terms of particular reactions. The method we are trying to use tends much more towards the study of a single reaction, whereas the bulk-horizon method gives the result of a set of frequently associated, but largely unknown, processes.

Properties of Clay Minerals

Introduction

Clay minerals are by definition minerals of high specific surface, and the part they play in soils is largely dominated by this fact. A study of the properties of clays therefore resolves itself into a study of their surface chemistry. The main objective of such work has been to relate the mineralogy of clays to their properties with the twofold result of being able to devise new tests to identify minerals and predict the properties of clays found in soils from a mineralogical analysis.

Expanding minerals

A superficial glance at the literature on clay minerals will quickly suggest that as a class of surface-active solids they are often rather unusual. There is, for example, a marked decrease in the surface areas available to non-polar substances, such as nitrogen and benzene, and that available to polar substances, such as water or pyridine. This has been traced to the entrance of the latter class of

compound, not only into clay aggregates, but also into the clay crystallites themselves. The latter process often occurs in a regular way, so regular that it is possible to investigate the swelling of the crystallites by the changing of the positions of X-ray reflections without any loss in their sharpness. This remarkable property has enabled the arrangement of the intercalated molecules to be studied, work that was first carried out by Hendricks in 1941. This aspect has received much attention at Rothamsted, several hundred organic complexes of a wide variety of chain and ring compounds having been investigated in recent years. A survey of the results shows that molecules that can behave as cations are strongly sorbed, whilst those that tend to be anions are weakly attracted. Among the " neutral " aliphatic compounds, those that are small and highly polar, such as methanol, are favoured, but in the aromatic series additional factors, due to distribution of the charge in the molecule and molecular polarizability, assume great importance. Since the internal surface may comprise up to 90 per cent of the total surface, these studies of the interaction of the internal surface with organic compounds are important in appreciating the classes of compound that interact strongly with soil clays.

Similar methods of study have been applied to the interaction of water and expanding clay minerals, but here the information has tended to be of a different kind, namely the relation between the swelling and the external vapour pressure. At low humidities the direct method is used, whereby the clay is allowed to come to equilibrium with definite relative vapour pressures of water vapour and the swelling determined from X-ray photographs. The results indicate that there is marked hysteresis between the wetting and drying cycles, but this is reduced when the swelling is plotted, not to the relative vapour pressure, but to the amount of water taken up. Although hysteresis prevents detailed thermodynamic study of the relation between vapour pressure and uptake, it can be clearly shown that the uptake by a mineral at a given pressure is dependent on the nature of the surface cations, those of high charge and small size promoting thicker films than those of low charge and large size. This result suggests that the formation of water films on clays is analogous to the hydration of cations in solutions; the primary process of sorption being one of forming a two-dimensional water shell round the cations. Whilst recent X-ray work has confirmed that this is essentially correct, it contradicts many of the older ideas on clay–water relations, which were often based on inadequate experimental data.

Investigations of the behaviour of expanding minerals at very high humidities have also been carried out in connection with the work on clay colloids pursued in the Physics department. Here the sample may be immersed in salt solutions of known concentration or brought to equilibrium with a known water-pressure deficiency. It is found that there is generally a sharply defined limit to the swelling of the crystallites, but cases occur, for example in sodium montmorillonite, where the swelling increases reversibly with vapour pressure to an indefinite extent and the X-ray patterns indicate a progressive decrease in order as the distance between the silicate sheets increases. Clearly, when the distance between the silicate sheets is of the order of 100 Å. the system approximates to that of

a true colloid, and it should be possible to test the current theories of quantitative colloidal behaviour with the resultant experimental data. When this is done it is found that the attraction between the silicate sheets drops off much less rapidly than would be expected, and it is concluded that present theories require drastic revision where they have to deal with the behaviour of clay particles.

As the internal surface becomes thickly covered with water molecules, the interlamellar cations are more easily able to move and become available to plants. With cations of low hydration energy, however, the exchange process is slow, due to the smaller amount of water on the surface, a phenomenon which in its aggravated form is known as cation fixation, and is of considerable practical importance in the case of potassium. The principal problem in potash fixation is to understand why it is severe in some soils and absent in others, that is to say, what is the relation between fixation and the nature of the soil minerals. In answer to this question a heartening advance has recently been made, since a correlation has been found between field fixation and the presence of a 14 Å. reflection (a vermiculite mineral) on the X-ray photographs of the glycerol-saturated clay.

Another kind of cation fixation that has been investigated is that which accompanies the dehydration of a certain class of montmorillonite minerals when saturated with small cations such as lithium. This effect, which is accompanied by loss of expanding properties, is apparently due to the migration of the surface cations into the silicate sheet and the filling up of certain vacant sites. Such sites must not only be vacant but they must also be near the seat of the negative charge in the silicate sheet. These conditions define fairly closely the minerals which give this effect, and it is easy to devise a test to distinguish them from minerals in the same group which give very similar X-ray photographs. This type of test has been found useful in examining the relation between soil clays and their parent materials, as well as in classifying the numerous montmorillonite minerals in the departmental collection. Another important use of this fixation effect has been to prepare minerals with known amounts of expanding and non-expanding silicate sheets and to study the X-ray and surface effects which appear. This has a bearing not only on the surface study of the partially expanding minerals in soils, but also on the fundamental theory of X-ray diffraction applied to such problems.

Non-expanding minerals

Whilst the study of expanding clay minerals has rightly received more attention in recent years, non-expanding minerals, e.g., kaolins are also being investigated. The non-expanding minerals are not as active in soils as the expanding minerals because of their much lower specific surfaces. The methods of investigation must therefore be correspondingly more sensitive, but since hysteresis effects are absent, the theoretical treatment of the results is simplified. On the whole the effects observed have much in common with what has already been described; the surfaces are more hygroscopic if the exchange cations have a high hydration energy, and anomalous effects are observed if a small cation like lithium is present.

UPTAKE OF NUTRIENTS FROM LEAF SPRAYS BY AGRICULTURAL CROPS

By

G. N. Thorne

Introduction

Interest in the application of fertilizers in sprays has increased in recent years because of the development of concentrated highly soluble fertilizers, and because the increasing use of machinery for spraying insecticides, weed-killers, etc., and for overhead irrigation, facilitates the application of nutrients in sprays. The effects of nutrient sprays are frequently ascribed to nutrient uptake by the leaves; for example such a claim is made by Secrett (1949) to explain the beneficial results obtained from the irrigation of a cauliflower crop with water containing 1 part in 20,000 of KNO_3. In an experiment on irrigated sugar beet, in which 12 inches of irrigation water were applied during the season, the application of nitrogen in the water caused a greater increase in the yield of tops than application to the soil at sowing (Results of field experiments for 1949, Rothamsted). However, in this experiment and in Secrett's irrigations the amount of water applied was so great that most of the contained nutrient must have fallen on the soil, and not been retained by the leaves, so that the difference between solid and spray application of fertilizer was probably not due to leaf absorption, but to the sustained supply of nutrients throughout the season, resulting from the repeated irrigations. Work was started at Rothamsted in 1950 to determine whether plants can absorb appreciable quantities of nutrients from leaf sprays, and to investigate the conditions that affect the amounts so absorbed.

Pot Experiments

Pot experiments were done in which the soil was protected so that the spray could not reach the roots (Thorne, 1954). Spraying barley, Brussels sprouts, French beans, tomato and sugar beet daily for several weeks with a solution containing nitrogen, phosphorus and potassium increased the content of all three nutrients and dry weight of plants of all the species. Increase in nutrient content occurred whether nutrient supply to the roots was high or low, and was approximately proportional to the concentration of nutrient in the spray and the frequency of spraying. Previously, Lewis (1936) had found that the phosphorus content, but not the nitrogen or potassium contents, of lettuces growing in a phosphorus-deficient soil was increased by spraying the leaves daily for 5 weeks with a solution containing nitrogen, phosphorus and potassium.

These experiments established that sprays containing several nutrients could increase the nutrient content of plants by as much as 100 per cent, and might in some circumstances cause similar increases in dry weight. They did not prove, however, that nitrogen, phosphorus and potassium were all absorbed by leaves, because absorp-

tion of one nutrient by the leaves might have increased uptake of others by the roots. In order to distinguish the effects of individual nutrients, sprays supplying nitrogen, phosphorus and potassium separately, and in all combinations, were tested on sugar beet (Thorne, 1955). All three nutrients were absorbed through the leaves, and uptake of any one of them was unaffected by the presence of others in the spray. Spraying with nitrogen-containing sprays increased the absorption of phosphorus and potassium by the roots from the soil, and potassium in sprays increased the uptake of phosphorus from the soil.

Nitrogen, but not phosphorus or potassium, fertilizer added to the soil increased the leaf area of sugar beet, and hence also the quantity of nitrogen retained and absorbed by the leaves from an ammonium nitrate spray (Thorne, 1955). None of the nutrients applied to the soil affected the percentage of the nitrogen retained on the leaf that entered the plant. Rodney (1952) showed that apple leaves absorb nitrogen equally easily from sprays of urea, calcium nitrate or ammonium sulphate, and the same result was found for sugar beet (Thorne, 1954). Urea is absorbed very quickly by the leaves of apple, and probably also other species (Cook and Boynton, 1952; Hinsvark *et al.*, 1953). In 2 hours the lower surface of young apple leaves absorbed 60 per cent of the applied urea and the upper surface 13 per cent; after 24 hours the corresponding figures were 80 and 20 per cent. Urea uptake by the lower surface during 2 hours was increased by high leaf nitrogen, unaffected by reducing the carbohydrate in the leaf by shading, and reduced by adding sucrose to the urea spray.

The amount of phosphorus retained and absorbed by leaves of sugar beet from a sodium phosphate spray was increased by nitrogen fertilizer added to the soil, and the percentage absorbed was also apparently slightly increased by nitrogen fertilizer, but unaffected by phosphorus or potassium (Thorne, 1955). Phosphorus uptake by the roots of swedes grown in a very high phosphorus nutrient solution was reduced when phosphorus was applied to the leaves (p. 66). The uptake of phosphorus from a variety of compounds supplied in sprays has been studied by Silberstein and Wittwer (1951), who found that the growth of tomato, maize and French-beans was increased by ortho-phosphoric acid and potassium and ammonium phosphates, but magnesium phosphate and most organic phosphates had little effect. Autoradiographs of whole plants of tomato, maize and French-bean, made a few hours after applying radio-active phosphorus to the leaves, showed that phosphorus is absorbed and translocated to other parts of the plant very rapidly (Silberstein and Wittwer, 1951; Wittwer and Lundahl, 1951). Absorption of ^{32}P by swede leaves increased for 2–3 days after a single application, and then remained constant for another 10 days at about 50 per cent of the amount applied (p. 67). Trebling the concentration of the solution applied to the leaves increased the percentage absorbed slightly, but significantly.

Potassium uptake by sugar-beet leaves from KCl sprays was increased by nitrogen applied to the soil in the same way as was nitrogen and phosphorus uptake. The percentage of the applied potassium absorbed by the leaves appeared to be slightly increased by nitrogen added to the soil, and reduced by potassium. The

latter effect may be due to reduced uptake by the roots of plants with a high supply of potassium from the soil when sprayed with potassium, because there was no accumulation of unabsorbed potassium on the surface of the leaves (*cf.* phosphorus uptake by swedes).

The quantity of nutrient remaining on the surface of sprayed leaves of sugar beet and removed by washing before harvest was small, showing that most of the nutrient retained by the leaves from sprays was absorbed. Therefore the percentage recoveries of nutrients from sprays were greater than those obtained from fertilizer applied to the soil at sowing (Thorne, 1955). Usually a slightly greater proportion of nutrient applied in sprays than of nutrient applied to the soil remained in the tops. The dry weight increases per unit of nutrient absorbed through the roots were greater than for nutrient absorbed through the leaves. Both these differences between nutrients applied to leaves and soil may be related to the later uptake from sprays; fertilizer nutrients were all applied to the soil at sowing, and those in the spray were supplied continuously throughout the growing season.

The mechanism of leaf absorption is not understood. Nutrients must be able to pass through the cuticle, because urea is absorbed by both surfaces of the hypostomatous apple leaf (Rodney, 1952; Cook and Boynton, 1952). Boynton (1954) claims that absorption also occurs through the stomata, but Fogg (1947) considers this unlikely on theoretical grounds. There is a continuous path of hydrophilic pectic substance from discontinuities in the cutin covering McIntosh apple leaves to the vascular bundle sheaths, along which water-soluble substances could pass (Roberts *et al.*, 1948). Absorption continues, however, long after the leaf is apparently dry, and spraying with water after a phosphate spray had dried did not increase phosphorus uptake by swede leaves (p. 67).

It can be concluded from pot experiments that nitrogen, phosphorus and potassium can all be absorbed by leaves from sprays and that most of the nutrient retained on the leaf is probably absorbed, often within a few days of application. Therefore recoveries in the plant of nutrients applied in sprays are normally greater than of nutrients applied to the soil. In spite of this, the effects on growth of nutrients applied in sprays were smaller than those of nutrients applied to the soil, but this difference would not necessarily occur in pots or in the field if fertilizers were applied simultaneously to soil and leaves.

Field Experiments

Nutrients supplied in sprays will only be absorbed by the leaves of field crops if the volume of solution applied per acre is sufficiently small for most of it to be retained by the leaves and not fall on the soil. Because of this limitation on the volume of spray solution, the quantity of nutrient that can be applied in a single spraying is restricted by the solubility of the fertilizers and the danger of scorching the leaves. Nitrogen is the best major nutrient for application by this method, because, as both urea and ammonium nitrate are highly soluble and rich in nitrogen, dilute solutions contain a relatively high concentration of nitrogen. Urea usually scorches less than ammonium nitrate.

Nitrogen uptake by sugar-beet plants from six sprays of 3 per cent ammonium nitrate or an equivalent urea solution, applied at 100 gal./acre in September, was twice that obtained from similar solutions applied to the soil between the rows (Report of Rothamsted Experimental Station for 1952, p. 67). Seventy per cent of the nitrogen applied in leaf sprays, whether as ammonium nitrate or urea, was recovered in the plant, and 30 per cent was converted into leaf protein. The distribution in the plant was the same for nitrogen absorbed through leaves or roots. In another experiment nitrogen uptake from four 3·4 per cent urea sprays, applied at 100 gal./acre or from one spray of 54·7 per cent urea applied at 25 gal./acre, did not differ significantly, although there was some scorching by the more concentrated spray (Report of Rothamsted Experimental Station for 1953, p. 70). Spraying winter wheat at ear emergence with 3 per cent NH_4NO_3 at 100 gal./acre increased the yield and nitrogen content of grain and straw to the same extent as applying the same solution to the soil at the same time (Report of Rothamsted Experimental Station for 1953, p. 70). Nitrogen applied as urea sprays also had the same effect as soil dressings of urea or other nitrogenous fertilizers on yield and nitrogen content of grass–clover leys, Italian ryegrass (Low and Armitage, 1954) and cereals when given in spring or ear-emergence application (Jealott's Hill, 1953). Urea solutions ranging in concentration from 11 to 44 per cent were used as sprays and applied at 20 gal./acre. Soil dressings and urea sprays have been shown to be equally effective methods of nitrogen application to tomatoes (Montelaro *et al.*, 1952), maize (Foy *et al.*, 1953) and sugar cane (Hawaiian Sugar Planters' Association, 1951). Urea sprays are frequently applied to apple trees, and give responses equal to, or better than, those obtained from soil dressings (Fisher 1952). Tolhurst and Bould (1952) have shown that nitrogen applied to apple trees as urea sprays does not kill the clover in the cover crop, as do soil dressings, and that trees grown in a non-leguminous sward benefit from urea sprays, whereas all the nitrogen in a soil dressing is utilized by the grass.

Spray application of phosphorus, which is easily fixed in the soil, might be an economical method of using the element, but phosphorus appears to have been applied in sprays much less frequently than nitrogen. This may be because annual agricultural crops require phosphorus early in the season when there is only a small leaf area to retain the spray, and because many phosphorus compounds have a low solubility. Silberstein and Wittwer (1951) report an experiment in which 2·7 lb. P_2O_5 per acre applied in four sprays of orthophosphoric or glycero-phosphoric acid increased the early yield of tomatoes more than did 135 lb. P_2O_5 per acre applied to the soil as superphosphate before transplanting. However, the total yield was significantly increased only by the soil dressing. Sugar cane is reported to respond well to 8 lb. P_2O_5 per acre applied as a superphosphate solution (Hawaiian Sugar Planters' Association, 1951).

Examples of spray application of potassium are also scarce, although the results that have been reported indicate that the method may be useful. The potash content of a crop of lucerne was increased 35 per cent by the application of 65 lb. K_2O per acre in four potassium sulphate sprays, and equivalent soil dressings gave only one-third this increase (Report of Rothamsted Experimental

Station for 1953, p. 70). The potash content of the crop was already high, and neither leaf nor soil application caused any increase in yield. Tropical crops might benefit from potash application in sprays, because many tropical soils are low in potassium and do not respond well to soil dressings. The yield of sugar cane and potassium per cent of dry weight of the sheaths were the same 5 months after receiving 19 lb. K_2O per acre as a spray as after 200 lb. K_2O applied to the soil (Hawaiian Sugar Planters' Association, 1951). The potassium spray was a 28·5 per cent solution of muriate of potash applied from the air at 10 gal./acre.

Nutrients can be applied in sprays with each other, with pesticides, herbicides, etc., or with trace elements. Several commercial highly soluble mixed fertilizers have been developed for application in solution to leaves or soil, and some have been used experimentally (Gillern, 1950; Arvan and Mowry, 1954; Pirone, 1952). The concentration of salts in a mixed nutrient spray is limited by their solubility and the danger of scorching, so that several applications are required to supply the same quantity of one nutrient as can be applied alone in a single spraying or as a soil dressing. When nutrients are added to fungicidal or insecticidal sprays the phytotoxicity may be increased. According to Hamilton *et al.* (1943), lime added to the spray reduced the injury to apple foliage caused by spraying with sodium or potassium nitrate or ammonium sulphate mixed with wettable sulphur and lead arsenate. Urea caused less damage than other forms of nitrogen when mixed with insecticides. Vegetable crops were damaged by sprays containing ammonium nitrate and arsenicals unless lime was also added, but urea was safe with a number of insecticides and fungicides (Isaacs and Hester, 1954). It is suggested that ammonium nitrate increases and lime decreases the solubility of the arsenates. A 51 per cent solution of ammonium nitrate or a 40 per cent solution of urea was safely applied to winter wheat in April, either alone or mixed with 2-4D (p. 67). Micronutrients can be mixed with major nutrients in sprays or applied alone, and the small quantities required can be easily supplied in a single dilute spray. Trace-element deficiencies are frequently due to soil conditions making the element unavailable to the plant, and are therefore often cured more easily by sprays than by soil application, e.g., manganese deficiency in peas and beetroot (Lewis, 1939; Wallace and Ogilvie, 1941) and boron deficiency in turnips (MacLachlan, 1944).

In field experiments the effects of nutrient sprays are usually of the same order as for soil dressings, and rarely more than two or three times greater. Therefore, spray application does not result in a great saving of fertilizer, but may be preferable to soil application when : (1) soil conditions or a competitive crop make nutrients from soil dressings unavailable; (2) an accurately timed response to fertilizer is required, e.g., a change in the composition of a crop late in the season; (3) routine applications of insecticidal or herbicidal sprays, to which nutrients can be added, are made; (4) the growth of the crop prevents application of fertilizer to the soil but permits it to the leaves from a high-clearance sprayer or helicopter. If crops are to absorb nutrients applied in sprays through their leaves there must be sufficient leaf surface to retain the spray. This limits the usefulness of the application of nutrients in sprays to annual

agricultural crops, because those most in need of fertilizer, i.e., young or starved crops, have only a small leaf area. Application of sprays is liable to be more expensive than traditional methods of fertilizer distribution, and therefore not economically justifiable, even when a saving in fertilizer results. Thus, although it is now well established that fertilizers applied in leaf sprays can be absorbed by crops and in some circumstances are more effective than fertilizers applied to the soil, the method is not likely to become very widespread. Apart from these practical considerations, nutrient absorption through leaves may prove very useful in theoretical studies on plant nutrition.

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CLASSIFIED LIST OF PUBLICATIONS

By

The Late E. M. Crowther

E. M. Crowther's work was scattered through a wide range of publications. The following list has been compiled to make it more accessible to workers in agricultural science.

Scientific Papers

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General Papers

1. Penman, H. L. (1954). Irrigation will increase production. *Fmr & Sth-Breed.* **68**, 13 & 14 April, p. 50.
2. Penman, H. L. (1954). Irrigation needs. *Soils & Fert.* **17**, 399.
3. Penman, H. L. (1954). Evaporation over the British Isles. *J. Instn Wat. Engrs.* **8**, 415. (Originally published in *Quart. J. R. met. Soc.* **76** (1950).)

Research Papers

4. Emerson, W. W. (1954). Limitations of existing methods for determining the stability of soil crumbs. *J. Soil Sci.* **5**, 233.

The breakdown of soil crumbs in conventional water-stability tests is a result of the combined effects of slaking and dispersion. The various factors influencing the effectiveness of these two processes have been divided into those determined by properties of the crumbs themselves and those dependent on the technique used. Two of the latter have been considered in detail, namely the method of wetting and the electrolyte content of the wetting liquid. It has been concluded from a comparison of the rates of water uptake by crumbs containing various amounts of organic matter that water has an appreciable advancing contact angle with air-dry organic matter. This may have been the main cause of the correlation found by previous workers between water stability and organic matter for soils high in organic matter.

It has been shown that calcium-saturated crumbs are metastable in distilled water but will disperse if mechanically disturbed. In conventional water-stability tests some continuous mechanical disturbance of the crumbs is inevitable, so that the apparent stability of the crumb always decreases with time. Also in these tests the crumbs are always immersed in a large excess of distilled water, so that the results obtained are independent of the calcium-ion concentration of the soil solution. In the field any increase in this concentration will make the crumbs more resistant to mechanical action.

5. Emerson, W. W. (1954). A new method for determining the stability of moist soil crumbs. *J. Soil Sci.* **5**, 240.

A new method for characterizing the stability of moist soil crumbs which avoids breakdown due to slaking has been described. The crumbs are slowly wetted under suction with a strong sodium chloride solution and then leached with this solution until sodium-saturated. The crumbs are then percolated with increasingly dilute concentrations of sodium chloride and the changes with time of the permeability of the crumbs and the concentration of salt in the leachate are measured. The concentration at which the crumbs completely break up and their permeability falls effectively to zero is called their critical concentration. The critical concentration for two plots from Barnfield 8O and 2N (the first having received no fertilizer or organic manure and the second 14 tons/acre farmyard manure and balanced artificial manuring annually for 80 years), and the adjoining permanent grass, with the same mineralogical constitution, were found to be 34, 5 and less than 0·3 mN. NaCl respectively, indicating the very marked differences in the cohesive strength of the crumbs.

By observing the effect of adding dilute alkali and acid on the concentration of electrolyte required to flocculate sodium-saturated suspensions of pure illite and montmorillonite, it was inferred that positive charges were present on the edges of the platelets, as shown already for kaolinite by Schofield and Samson (1953). The flocculation concentration for illite with sodium alginate added was found to be between 250 and 300 mN. NaCl. This agrees well with determinations of the flocculation concentration for montmorillonite and kaolinite found by other workers using certain large organic molecules.

The flocculation concentrations of sodium-saturated suspensions of the Barnfield 8O and Willaluka soils were found to be equal, namely 30 mN. NaCl.

This is the same as the critical concentration for crumbs of these soils. In the virtual absence of organic matter, therefore, flocculation appears to be a reversible state of equilibrium. The concentration of NaCl required to flocculate sodium-saturated suspensions of the grassland soil was 200 mN., which is about the same as that for suspensions of pure clay minerals in the presence of grassland crumbs.

It is suggested that the additional cohesive force of grassland crumbs is due to linkage of the positive edges of clay crystals by long-chain organic molecules. The reduced attractive forces in suspensions of the grassland soil compared with Barnfield 8O soil may be due to the absence of positive edge–negative face attraction as a result of each molecule being linked to the edge of one clay crystal only.

6. Emerson, W. W. (1954). Water conduction by severed grass roots. *J. agric. Sci.* **45**, 241.

It is suggested that part of the increased permeability of soil recently ploughed out from grass could be due to water conduction through severed roots. Microtome sectioning of a root of *Lolium p.* showed a continuous metaxylem element of about 30 μ diameter, with only minor restriction, forming a natural capillary tube. Further, being at the centre of the stele, the metaxylem should persist for some time after the grass has been killed. Hydraulic diameters calculated from laboratory experiments on the rates of water conduction by several *Lolium p.* roots were in reasonable agreement with the diameter of the metaxylem measured by direct sectioning.

Similar experiments on *Phleum p.* were more difficult to interpret due to the complexity of the metaxylem, the number of elements not being constant along the root. The rate of water conduction by roots of *Dactylis g.* was found to be small compared with the other grasses, for although having the largest number of elements, they are the smallest in size of any grass examined.

The permeability of a severed *Lolium p.* root system, calculated on the basis of the surface density of roots found on 4-year-old plots, indicated that the root system should significantly increase the unsaturated permeability of soil at low suctions. To obtain maximum benefit the "capillary tubes" should be severed immediately under the turf and not at ploughing depth. Accordingly, two plots were laid out on old grassland to compare normal autumn ploughing with shallow rototilling on the subsequent germination and growth of spring wheat. In spite of repeated rototilling, however, it proved impossible to kill the grass in the wet winter conditions, and the wheat was smothered. A comparison of the suctions developed at 5 cm. in the two plots showed that the unsaturated permeability of the rototilled plot was higher.

Although the laboratory results are encouraging, there is as yet no conclusive evidence that the natural water supply and drainage system formed by the severed roots is important under field conditions.

7. Emerson, W. W. (1955). The rate of water uptake of soil crumbs at low suctions. *J. Soil Sci.* **6**, 147.

Soil crumbs dried initially to the wilting point have been slowly percolated with $1 \times 10^{-2}M$. calcium chloride through a capillary siphon. It has been shown by weighing the crumb at intervals that although excess solution is discharged from its base, after the first or second day the crumb continues to take up solution at a decreasing rate over the next 3 months. This is attributed to the re-arrangement of the individual clay crystals, as the thickness of the water films on the crystals increases with decreasing suction. It has been shown theoretically that the equilibrium thickness of these films will increase markedly as the suction approaches zero.

The slow swelling of the clay will be accompanied by a corresponding decrease in the permeability of the crumbs as the larger pores are reduced in size. This is of great practical importance in the drainage of heavy clay soils, since it means that the permeability of the soil as a whole may be improved over the winter by using a deep-rooted crop to dry the subsoil out during the summer. This has been shown by comparing the drainage records of three fields; one after fallow, one after winter wheat and the third in permanent grass on the Gault of the Cambridge University Farm for the winter of 1932–33. It was also possible to infer from the dates at which the drains started running and the volume of water discharged that considerable delayed water uptake occurs as the clay slowly swells.

Delayed swelling also affects the concept of field capacity, since the moisture content of the soil at " field capacity " will increase during the winter with each succeeding fall of rain.

8. Emerson, W. W. (July 1954). The effect of various grasses and lucerne on the cohesion of soil crumbs. *5th int. Congr. Soil Sci.*

The increase in crumb cohesion produced in 4-year-old herbage plots on an old arable field has been measured by a new sodium saturation technique. The grasses examined appear to be similar in their structure-forming ability, but lucerne is relatively ineffective. The principal difference between the improvement in crumb stability under a ley and under very old grassland seems to be the depth to which this improvement extends.

9. Emerson, W. W. (1955). A note on the sodium saturation test for determining the stability of moist soil crumbs. *J. Soil Sci.* **6**, 160.

10. Penman, H. L. Evaporation over parts of Europe. *Ass. int. Hydrologie sci.*, Rome 1954. (To be published.)

Weather records from thirty-one meteorological stations in Europe are used to calculate the potential evaporation rate from neighbouring land surfaces and thence the estimated actual evaporation rate after correcting for shortage of summer rainfall. In northern Europe special consideration has had to be given to periods when snow covers the ground. Annual values range from about 20 cm./year in northern Norway to 60 cm./year in Italy and the Balkans; from west to east there is little change in total between Britain and Russia near Moscow, though the seasonal distribution differs markedly. A general check has been obtained from mean annual values of rainfall and run-off from forty-four catchment areas—not so well distributed as the weather stations—and the agreement is usually within 10 per cent in comparable environments.

11. Penman, H. L. (1955). Components in the water balance of a catchment area. *Quart. J. R. met. Soc.* (In the press.)

The paper presents and discusses data on the amplitudes and phases of the annual changes in monthly rainfall, run-off, ground water storage, evaporation and soil moisture deficit over a period of 5 years (1931–36) for the Thames basin above Teddington Weir.

12. Schofield, R. K. & Taylor, A. W. (1955). Measurements of the activities of bases in soils. *J. Soil Sci.* **6**, 137.

The activities of aluminium, calcium, potassium and sodium hydroxides have been determined in suspensions of soil chloride solutions of widely differing concentrations by measuring the ratio of activity of the metal chloride to the activity of hydrochloric acid. This procedure avoids the uncertainties inherent in attempts to measure the activities of individual ions.

For each of the four ions used there is a range of dilute chloride solutions within which the hydroxide activity is easily measurable and is nearly independent of the chloride concentration. The method is inapplicable in the absence of chloride, and experimental difficulties were encountered at the lowest concentrations used.

At higher salt concentrations there is a distinct rise in the hydroxide activity with increase in salt concentration. Both this rise and the substantial constancy at the lower chloride concentrations are to be expected for suspensions of negatively charged colloids exerting buffer action. The constant hydroxide activity approached as the chloride concentration is reduced is evidently a characteristic of the soil sample in question.

13. Schofield, R. K. & Taylor, A. W. (1954). The hydrolysis of aluminium salt solutions. *J. chem. Soc.* p. 4445.

The value of the equilibrium constant of the reaction $(Al,6H_2O)^{3+} + H_2O \rightleftharpoons (AlOH,5H_2O)^{2+} + H_3O^+$ has been determined by direct measurement of the pH values of a series of aluminium salt solutions, and a pK value of 4·98 at 25° C. ($K = 1{\cdot}05 \times 10^{-5}$) has been obtained. The temperature coefficient of −0·03 units/° C. suggests that the mechanism of the reaction is similar to the

dissociation of water. The results obtained are compared with those of a previous determination by Brönsted and Volquartz (*Z. phys. Chem.* 1928, **97**, 134).

Chemistry Department

General Papers

14. Bremner, J. M. (1955). Recent work on soil organic matter at Rothamsted. *Z. PflErnähr. Düng.* (In the press.)

Results obtained at Rothamsted in recent work on the nitrogenous and lignin-like complexes of soil are discussed. (Paper read at Conference on Soil Organic Matter at Braunschweig, Germany, 31 March–4 April, 1954.)

15. Cooke, G. W. (1954). Fertilizer placement. *FATIS Review*, no. 3, p. 8 (O.E.E.C., Paris).

A general account of fertilizer placement research in England. The advantages of placement for all important crops are stated. A brief account of fertilizer placement research in other European countries is also given.

16. Cooke, G. W. (1954). The importance of organic matter in relation to crop nutrition. *Bull. Cent. int. Engrais chim.* no. 2 (December 1954), p. 7.

A review of the functions of organic matter in crop production.

17. Cooke, G. W. (1954). Off to a good start—with phosphate. *Fmr & Stk-Breed.* 7 September, p. 69.

An article for farmers. The uses of various types of phosphate fertilisers are described. The value of rock phosphates for certain crops on acid soils is stressed, as are the benefits of water-soluble phosphate for starting crops. Methods of maintaining soil phosphate reserves are described.

18. Cooke, G. W. (1954). The use of fertilizers for peas. *E. Riding Fmrs' J.* **6**, 26.

Experiments testing the value of fertilizers for peas are described. Nitrogen and phosphate gave little or no response when broadcast for threshed peas; there were small but consistent gains from broadcast potash fertilizer. When dressings of phosphate–potash fertilizer were placed at the side of the seed, larger and more profitable responses were obtained. The value of soil analysis in making recommendations for manuring peas is stressed.

19. Cooke, G. W. (1954). Nitrogen and phosphorus fertilisers in North-Western Europe. *Proc. Fertil. Soc.* no. 27.

The amounts of fertilizer used in several European countries are stated, and current trends in consumption are examined. As fertilizer usage expands there is a tendency for the amounts of nitrogen and potassium to increase more rapidly than the amounts of phosphorus. The forms of nitrogen and phosphorus fertilizers used in different countries are examined. Consumption of ammonium nitrate (usually as mixtures with limestone) has increased rapidly in several countries, increases in usage of other nitrogen fertilizers have been smaller. Superphosphate and basic slag supply most of the phosphorus used in North-Western Europe. In the United Kingdom and France large proportions of the nitrogen and phosphorus used are sold in the form of compound fertilizers; compounds are relatively uncommon in other countries.

The manufacture and use of dicalcium phosphate and nitrophosphates as alternatives to superphosphate are described. The valuation of these fertilizers in France, Belgium, Holland and the United Kingdom by laboratory tests and by glasshouse and field experiments is discussed. British experience does not confirm the Continental view that agricultural tests on powdered dicalcium phosphate dihydrate can be used as evidence on the value of granulated compound fertilizers containing anhydrous dicalcium phosphate. In Britain

the immediate effects of phosphorus fertilizers are stressed, but in other countries the residual effects are emphasized. The physical properties of granular fertilizers containing water-insoluble phosphate may be very important, and some of the agricultural value of dicalcium phosphate may be lost when it is granulated. The agricultural superiority of fine powders and the superiority of coarse granules in production and for distribution may be reconciled by making granules which break up rapidly when wetted. Granular products are usually ground before they are analysed, and the results of solubility tests on the ground products apply only to such powders. Grinding may obscure physical properties of granules—such as the presence of a hard surface skin—which are important agriculturally.

The newer types of processes which produce phosphorus fertilizers insoluble in water are discussed in relation to possible expansion and changes in fertiliser production in Britain. It is possible that nitrophosphates or ammoniated superphosphate may be made here. Both kinds of fertilizers contain dicalcium phosphate. Much more laboratory and field work is necessary before a precise valuation can be made of water-insoluble phosphorus contained in granular fertilizers. Conventional extractants may be satisfactory for powdered fertilizers, but they are not likely to be satisfactory for valuing granular materials. The valuation of granulated insoluble phosphates is an urgent and important problem which must be solved before such materials can be introduced widely in this country.

20. Cooke, G. W. & Garner, H. V. (1954). The importance of organic matter in crop production. *J. R. agric. Soc.* **115**, 27.

Organic matter is not essential for plant growth, but in normal cropping it influences supplies of nutrients, water and air. The value of organic manures to farmers must be measured by field experiments. By testing fertilizers at the same time it is possible to estimate how much importance should be given to the nutrients supplied by the organic matter. Increases in crops over those caused by the added nutrients may be ascribed to improvements in soil "condition".

Older continuous experiments show that adequate fertilizers, continuously applied, may give as good or better crops than farmyard manure. More recent annual experiments show that extra yields are produced by using organic manures for crops which received fertilizers as well. No modern experiments in Britain have tested organic manures in the presence of optimum fertilizer dressings. Until this is done the physical effects of organic manures cannot be measured with certainty.

Methods of maintaining soil fertility by organic manures are discussed. Ploughing-in straw may reduce yields unless adequate nitrogen is applied; much of the value of straw lies in the potassium it contains. Straw composts are uneconomic if there are serious losses of plant food in the composting process.

Organic matter may be added to soils by ploughing in green manures or leys. There is no certain evidence that green manures improve soil condition, since much of the organic matter they contain is rapidly oxidized. If temporary leys are used to keep up fertility they must be dressed with nitrogen unless they contain abundant clover. Increased yields following ploughed-up leys have been demonstrated; the effects are partly due to improvements in soil structure and partly to nitrogen fixed by legumes. Where the system of management results in much herbage being removed from a field, there may be a serious drain on soil potassium. Unless extra potassium fertilizers are given the yields of arable crops following the ley may be reduced.

The following suggestions are made: (i) On *coarse, sandy soils*, where aeration and drainage are good, additions of organic matter are not *essential* for fairly good yields, providing adequate lime and fertilizers are given. (ii) On *clay soils*, where the actions of frost or judicious cultivations produce stable crumb structure, the physical improvements following extra organic matter are not essential for profitable cropping, provided sufficient fertilizer is used. (iii) On other soils, usually consisting of fine sand and silt, some action must be taken to maintain structure if profitable arable crops are to be grown. These soils become difficult to work as organic matter falls, crumbs formed by cultivation are not water-stable and the soils "run together" and cap in wet weather. The problem in farming such intractable soils is that of maintaining income levels while growing grass or other crops which build stable crumb structure.

21. Crowther, E. M. (1954). The production and use of fertilizers : some current trends and problems. Jubilee Memorial Lecture of the Society of Chemical Industry. *Chem. & Ind.* 1400.

The lecture presents by means of diagrams a critical survey of the world uses of the main fertilizer elements. The long trend of world production of phosphate rock, rising from 5,000 tons per annum in 1850 to 25,000,000 at the present time, has been very near to doubling every 10 years. This is a biological type of growth, and is interpreted as growth of a body of knowledge likely to extend far into the future. The present tendency is for the use of N and K to increase more rapidly than P. Countries like India use only one-hundred part of the amounts used by countries like Holland. Countries with settled agricultural systems, such as Western Europe, tend to use about equal amounts of N, P_2O_5 and K, while those with mainly irrigated farming use mainly N, and pastoral district mainly P.

In the United Kingdom the use of N and K trebled and P doubled in the period 1939-54, but in spite of this the use on most crops is well below the most profitable dressings which have been established by experimental field work. These optimum rates are given for various crops with adjustments to be made to allow for different soils and climates and for varying price relationships. It is pointed out that in the past experiments to compare different kinds or rates of fertilizer have very often been rendered unsuitable for this purpose because the rates chosen have been too high to extend into the sensitive range. Residual values of prolonged P and K treatments are dealt with and the effectiveness of the special placement of these elements as starter doses for crops.

A close study is made of the significance of ratios and limits of variation in the definition of compound fertilizers, and a strong plea is made for the advantages which could accrue from rationalizing and simplifying present codes.

The main purpose of fertilizer is not to maintain soil fertility but to raise it so that new kinds of crops can be grown profitably and more cheaply under better and more productive systems of farming.

Research Papers

22. Bremner, J. M. (1955). Nitrogen transformations during the biological decomposition of straw composted with inorganic nitrogen. *J. agric. Sci.* (In the press.)

Nitrogen transformations during the decomposition of straw composted with ammonium carbonate were studied by following the changes in : (*a*) the amounts of inorganic and organic nitrogen; (*b*) the amounts of ammonia-volatile base-, α-amino- and amino-sugar-N liberated by acid hydrolysis of the organic nitrogen complexes; and (*c*) the amino-acid composition of acid hydrolysates of the composts. The results showed that synthesis of organic nitrogen during the biological decomposition of straw composted with ammonium carbonate was not accompanied by any gross change in the distribution of the forms of organic nitrogen. A large fraction of the organic nitrogen synthesized was in the form of protein; a smaller fraction was in the form of amino-sugar. The amino-acid composition of acid hydrolysates of the rotted and unrotted straws were not greatly different. The rotted, but not the unrotted, straw hydrolysates contained β-alanine and a substance provisionally identified as α, ε-diaminopimelic acid.

23. Bremner, J. M. (1954). Identification of hydroxylamine and hydrazine by paper chromatography. *Analyst*, **79**, 198.

A method for the separation and identification of microgram quantities of hydroxylamine and hydrazine is described. It involves paper chromatography with acidic solvents and identification by R_F values and by the colours produced with picryl chloride and other detecting reagents.

24. Bremner, J. M. (1954). A review of recent work on soil organic matter. Part II. *J. Soil Sci.* **5**, 214.

A review of recent work on the extraction and fractionation of soil organic matter, the interaction of organic and inorganic soil colloids, the humic and fulvic fractions and the lignin-like complexes of soil organic matter.

25. Bremner, J. M. & Shaw, K. (1954). Studies on the estimation and decomposition of amino sugars in soil. *J. agric. Sci.* **44**, 152.

The amounts of amino-sugar-N present in acid hydrolysates of six soils with nitrogen contents ranging from 0·17 to 2·82 per cent have been estimated by colorimetric and alkaline decomposition methods. Recovery of amino-sugar-N after hydrolysis of chitin or glucosamine was found to be unaffected by the presence of soil during hydrolysis. Substances known to interfere with the methods of amino-sugar analysis employed were not detectable in the soil hydrolysates. From the amounts of amino-sugar-N liberated by acid hydrolysis it is deduced that 5–10 per cent of the total nitrogen of the soils examined was in the form of amino-sugars. The decomposition of amino-sugars in soils has been studied by comparing the rates of decomposition of chitin, glucosamine, casein and yeast nucleic acid when incubated with soil under conditions found to produce rapid nitrification of ammonium sulphate. Glucosamine and chitin are readily decomposed by soil micro-organisms, but not so rapidly as casein or yeast nucleic acid.

26. Cooke, G. W. (1954). Recent advances in fertilizer placement. II. Fertilizer placement in England. *J. Sci. Fd Agric.* **5**, 429.

Phosphorus and potassium fertilizers used for cereals should be drilled with the seed; half dressings applied in this way have produced as much grain as full-dressings broadcast.

Where potatoes are hand-planted in furrows, fertilizer may be concentrated near the seed satisfactorily by broadcasting it over the furrows before planting. When a mechanical potato planter was used on flat land, fertilizer dressings applied in bands beside the seed produced higher yields and more profit than broadcast dressings.

Fertilizer placed near the seed produced higher yields of beans and peas and several kinds of horticultural crops than the same quantities of broadcast fertilizer. For high-value cash crops, placement may be very profitable. Absence of crop responses in field experiments may be due to fertilizers having been applied in the wrong place.

Some crops, e.g., sugar beet, mangolds and kale, made better early growth when complete NPK fertilizer was placed beside the seed than when fertilizer was broadcast, but at harvest the two methods of application gave similar yields.

PK fertilizers broadcast over established temporary and permanent herbage crops gave higher yields than dressings placed in bands below the surface. Placing PK fertilizers in bands at the side of lucerne seed was not superior to broadcasting. When light dressings of superphosphate were placed directly below the seed as a " starter ", lucerne grew more rapidly and produced higher yields than when superphosphate was broadcast.

Fertilizers broadcast and incorporated deeply with the soil have advantages over dressings worked in shallowly in dry seasons and for deep-rooting crops.

Root growth of most crops was stimulated by dressings of mixed fertilizers placed near the seed. Nitrogen, phosphorus and potassium fertilizers placed near the seed of peas each stimulated extra root growth. The factors that affect the value of fertilizer dressings are discussed, with particular reference to the kinds of root systems developed by crops.

27. Cooke, G. W. & Nixon, H. L. (1955). The value of sewage sludge ashes as phosphorus fertilizers. *J. Sci. Fd Agric.* **6**, 79.

When sewage sludge is incinerated, the ash contains most of the phosphorus present in the sludge. The fertilizer value of phosphorus in ashes prepared from three sewage sludges was investigated by pot experiments.

One sludge prepared from domestic sewage contained phosphorus which appeared to be equivalent to water-soluble phosphorus in a pot experiment on turnips. After this sludge was burnt at 900° the phosphorus in the ash remaining was of very little value.

Three sewage sludges were burned at approximately 350°, 600° and 900°, and the ashes were compared as phosphorus fertilizers with superphosphate in a pot experiment on radishes. Ashes prepared at low temperatures contained phosphorus of some value to radishes. Ashes prepared at higher temperatures from two digested sludges containing some calcium carbonate were useless. High-temperature burning of a third sludge prepared by acid precipitation

from sewage containing wool residues gave products which had some value as phosphorus fertilizers.

The 2 per cent citric acid test used for basic slags did not differentiate between sewage sludge ashes of varying fertilizer value.

Ash remaining after burning most sludges is not likely to have much value as a phosphorus fertilizer, but any product made in quantity may be worth biological testing.

28. Crowther, E. M., Warren, R. G. & Benzian, B. (1954). Nutrition problems in forest nurseries, Summary report for 1952. *Rep. For. Res., For. Comm., for 1952–53*, 84.

29. Haines, W. B., Crowther, E. M. & Thornton, G. J. (1954). Manuring heavea. V: Long-term effects in the Dunlop (Malayan) experiments. *Emp. J. exp. Agric.* **22**. (In the press.)

The paper reports growth and yield measurements taken after the Japanese Occupation on experiments with rubber trees of many years standing. Treatments went on from 1934 until 1941, and then ceased. The measurements reported were made in 1948, and showed that on the whole the trees had maintained the advantages gained earlier, while in some cases there had been further gains attributed to effects of residuals. Measurements are given to show the considerable gains which boundary trees may make by poaching fertilizer from neighbouring plots.

30. Talibudeen, O. (1954). The determination of isotopically exchangeable phosphorus in some Rothamsted soils. *Proc. Radio-Isotope Conf.*, Atomic Energy Research Establishment, Harwell, **1**, 405.

A method is suggested for determining the surface phosphorus in soils by measuring the true "surface exchange" of the orthophosphate ion. "Surface phosphorus" and "isotopically exchangeable phosphorus" values of five Rothamsted soils varying in their previous cropping and manuring, the pH of their soil solution, and their $CaCO_3$ content, are determined. In preliminary experiments it is also shown how the method can be used to investigate: (*a*) the recovery of added phosphorus, and (*b*) the nature of soil phosphate, in two soils.

31. Talibudeen, O. (1955). Complex formation between montmorillonoid clays and amino-acids and proteins. *Trans. Faraday Soc.* **51**, 582.

The stability of complexes formed by montmorillonite with amino-acids and proteins is found to increase as the cationic nature of the zwitterion predominates increasingly. Accurate measurement of the $d(001)$ spacing of the complexes is made possible by the use of oriented montmorillonite flakes for adsorption. The differences between the observed and calculated Van der Waal thicknesses of adsorbed amino-acid molecules is ascribed to H-bonding of the C—H---O type. This information is used to derive the actual thicknesses of one and two close-packed polypeptide chains of the β-keratin type.

Pedology Department

32. Bloomfield, C. (1955). The deflocculation of kaolin by tree leaf leachates. *Trans. 5th int. Congr. Soil Sci.* (In the press.)

Texture differentiation, often found in podzolized soils, may result from the accumulation of clay in the B horizon. Results reported here indicate that physical transportation of clay can result from the action of rain-water containing organic compounds leached from the A_0 horizon. The aqueous leachates of some fifteen species of broad-leaved and coniferous trees, at low concentrations, have a marked deflocculating effect on kaolin suspensions. In most cases, as the concentration of plant extract is increased, the extent of deflocculation reaches a maximum and then decreases, more or less abruptly depending on the species.

O

33. Bloomfield, C. (1955). The movement of sesquioxides and clay in the soil. *Afr. Soils, Paris.* (In the press.)

A review of work on the effect of plant-remains on soil sesquioxides.

34. Brown, G. (1954). Degrading Illite and potash fixation. *Nature, Lond.* **173**, 644.

Irish soils found to fix potassium contained " degrading illite ". The diffraction patterns of air-dry clay in an evacuated camera show a band from 10 Å. to higher spacings which generally merges with the background at 12–13 Å. and never extends beyond 14 Å. Treating the clay with glycerol causes the band to resolve into lines at 10 Å. and 14 Å., and heating at 350° C. for 12 hours causes the band to disappear. It is suggested that " degrading illite " fixes potassium.

35. Brown, G. & Greene-Kelly, R. (1954). X-ray diffraction by a randomly interstratified clay mineral. *Acta cryst., Camb.* **7**, 101.

Preheated lithium montmorillonite when treated with glycerol shows random interstratification effects which appear to follow those predicted by the Hendricks and Teller treatment for a two-component system of 9·4 and 17·7 Å. repeat distances.

36. Greene-Kelly, R. (1955). Sorption of aromatic compounds by montmorillonite. Parts I & II. *Trans. Faraday Soc.* (In the press.)

Part I. The sorption complexes of montmorillonite and aromatic molecules have been studied by X-ray spacing measurements and one-dimensional Fourier synthesis. The results have shown that two orientations are common. The first, which is generally stable at low surface concentrations, has the plane of the ring of the molecule parallel to that of the silicate sheet, but at higher surface concentrations the molecules reorient so that their planes are perpendicular to that of the silicate sheet. The contact distances between the surface oxygens of the silicate sheet and the atoms of the organic molecules have been confirmed as being shorter than the normal Van der Waal's distance. It has been found, however, that the calculated shortening does not vary much between complexes, provided the correct structure is allocated.

Part II. Vapour- and liquid-phase isotherms have been determined for the montmorillonite–pyridine system. The simultaneous examination of the adsorbent by X-ray diffraction has permitted the points on the isotherm corresponding to orientation changes of the sorbed pyridine to be identified. In the light of this evidence the packing of pyridine between the silicate sheets of montmorillonite is discussed.

37. Greene-Kelly, R. (1955). Dehydration of the montmorillonite minerals. *Miner. Mag.* (In the press.)

Neither of the two closely related systems, Li–montmorillonite–beidellite and Li–Na–montmorillonite is a uniform one. In the former it seems that there must be differences in composition between silicate sheets bound in the same crystallite, and in the latter the majority of the sodium ions aggregate to form a sodium-rich " phase ". The effect of heating on the internal surface available to glycerol of the Li-saturated montmorillonite–beidellite is shown to be correlated with the amount of octahedral substitution, less than 70 per cent leading to some glycerol penetration. In the Li–Na–montmorillonite system, if there is less than 70 per cent Li ions in the interlamellar spaces, expansion also occurred after heating. No evidence was found of an intermediate state of expansion at 14 Å.

38. Singh, S. (1954). A Study of black cotton soils with special reference to their coloration. *J. Soil Sci.* **5**, 289.

Treatment of calcareous soils with H_2O_2 has almost no effect on their coloration if MnO_2 is present, but destruction of this and carbonate leads to decoloration. The apparent resistance of the organic carbon of black soils compared with the associated red soils is due to Ca-saturation. The clay fractions of the black contain less resistant carbon than those of the red soils. The regur soils of central and peninsular India and the " Kabar " soils of

Bundelkland contain organic matter which behaves similarly on peroxidation to that of the " Karail " soils of the Gangetic alluvium, suggesting that their formation occurs under somewhat similar intermittent anaerobic conditions.

39. (Smithson, F.) (1954). The petrography of dickite sandstones in North Wales and Northern England, with an Appendix on the differentiation of dickite and kaolinite by G. Brown. *Geol. Mag.* **91**, 177.

The identifications were divided into four classes, and the appendix explains their significance.

40. Stephen, I. (1954). An occurrence of palygorskite in the Shetland Isles. *Miner. Mag.* **30**, 471.

Palygorskite occurring in montmorillonitized syenite has been studied by optical, X-ray and chemical methods and by D.T.A. and electron microscopy. Samples of other minerals, known as pilolite (Heddle, 1879, *Miner. Mag.* **2**, 206), " mountain leather " and " mountain cork ", have also been examined, and these have been found to give X-ray diagrams identical with that of the Shetland Palygorskite.

Soil Microbiology Department

41. Bromfield, S. M. (1954). Reduction of ferric compounds by soil bacteria. *J. gen. Microbiol.* **11**, 1.

Reduction of ferric lactate by washed-cell suspensions of *Bacillus circulans*, *B. megaterium* and *Aerobacter aerogenes* takes place in the presence of suitable hydrogen donors. Ferric hydroxide is reduced when $\alpha\alpha'$-dipyridyl is present in the cell + substrate system. The reduction of ferric compounds by washed cells + substrate is similar to the reduction of methylene blue. Culture fluids of *B. circulans* do not reduce ferric iron in the absence of normal cells.

42. Kleczkowska, J. & Kleczkowski, A. (1954). The effect of ribonuclease on phage–host interaction. *J. gen. Microbiol.* **11**, 451.

Pancreatic ribonuclease inhibits the multiplication of a Rhizobium bacteriophage in liquid bacterial cultures by preventing permanent combination between phage and host. The addition of ribonuclease after phage has already combined with the bacteria does not prevent phage from multiplying, but it does decrease the rate of multiplication; the enzyme also interferes with multiplication of the bacteria. Experiments with ribonuclease in conjunction with chymotrypsin suggest that phage and bacteria unite in the presence of ribonuclease but that the union is only transitory and ends by the release of still active phage. In the presence of chymotrypsin, however, the phage becomes inactive during this transient union.

43. Meiklejohn, J. (1954). Some aspects of the physiology of the nitrifying bacteria. In *5th Symp. Soc. gen. Microbiol.* (' Autotrophic micro-organisms '), p. 68.

44. Meiklejohn, J. (1954). Microbiology of the soil. *Biology*, **19**, 107.

45. Meiklejohn, J. (1954). Notes on nitrogen-fixing bacteria from East African soils. *Trans. 5th Int. Congr. Soil Sci.* (In the press.)

About forty samples of East African soils were examined for the presence of nitrogen-fixing bacteria. An impure culture of *Azotobacter* sp. was obtained from a calcareous sandy soil, but this was the only sample of those examined which contained *Azotobacter*. Anaerobic nitrogen-fixing *Clostridium* spp. were isolated from every sample. A species of *Beijerinckia* which forms a green fluorescent pigment, and which is an effective nitrogen-fixer, was isolated from an acid sandy soil (pH 4·5).

46. Meiklejohn, J. (1955). The effect of bush burning on the microflora of a Kenya upland soil. *J. Soil Sci.* (In the press.)

Soil samples were taken from the surface of three sites at Muguga, Kenya, before and at intervals after the vegetation covering the sites was burnt.

The numbers of micro-organisms estimated by a direct-counting method fell after burning on all three sites.

There was also a reduction after burning in the numbers estimated by plate counts, especially in the number of fungi, which disappeared completely for a time on two of the sites.

Aerobic nitrogen-fixers are apparently killed by burning; but anaerobic nitrogen-fixers, though not very efficient at any time, appear to survive burning.

The nitrifying bacteria are either killed or reduced to very few by burning.

47. Nutman, P. S. (1954). Symbiotic effectiveness in nodulated red clover. I. Variation in host and in bacteria. *Heredity*, **8**, 35.

From a comparative study in red clover of variation in symbiotic effectiveness, the following results were obtained :

(1) With effective or partially effective strains of bacteria, the response of individual plants in a variety, in terms of amount of growth made on nitrogen-free medium showed a skew distribution.

(2) In general, distribution curves of host response with such strains show a primary mode of effectively, and a secondary mode of ineffectively responding plants.

(3) The relative sizes, but not usually the positions, of these modes vary with bacterial strain.

(4) With ineffective strains of bacteria the distribution curve is negatively skew and shows a single mode only.

(5) Preliminary breeding experiments show that the host-plant differences are inherited.

48. Nutman, P. S. (1954). Symbiotic effectiveness in nodulated red clover. II. A major gene for ineffectiveness in the host. *Heredity*, **8**, 47.

Clover plants with a simple recessive host factor, i_1, show a completely ineffective response when inoculated with the normally effective bacterial strain A. Plants homozygous for i_1 give an effective response with other effective strains of bacteria unrelated to strain A as well as with a stable variant of strain A (substrain A211). Other bacterial variants of strain A were isolated which give rise to mixed responses in i_1 homozygotes. A recessive suppressor m_1 is also inferred which restores $i_1\, i_1$ plants to complete effectiveness with strain A.

49. Skinner, F. A. (1955). Antibiotics. In Modern methods of plant analysis. Edited by K. Paech & M. V. Tracey, vol. 3. Berlin: Springer-Verlag. (In the press.)

50. Stevenson, I. L. (1954). Antibiotic production by actinomycetes in soil demonstrated by morphological changes induced in *Helminthosporium sativum*. *Nature, Lond.* **174**, 598.

A preliminary account of studies dealing with the presence and activity of antibiotics in soil, particularly in micro environments. Use is made of a new technique for the detection of soil antibiotics based on the effects of these substances on the morphology of the test fungus.

51. Stevenson, I. L. (1954). Antibiotic production by actinomycetes in soil and their effect on root-rot of wheat. *8th Int. Congr. Bot.* Sect. 24, p. 69.

52. Thornton, H. G. (1954). The nodule bacteria and their host legumes : some problems that they still present. *Sci. Progr.* no. 166, 185.

53. Treccani, V., Walker, N. & Wiltshire, G. H. (1954). The metabolism of naphthalene by soil bacteria. *J. gen. Microbiol.* **11**, 341.

The early stages in the oxidation of naphthalene by five micro-organisms were investigated. In all the organisms D-*trans*-1 : 2-dihydro-1 : 2-dihydroxynaphthalene, salicylic acid and catechol appeared to be intermediate oxidation products. Washed cells grown on naphthalene oxidized α- and β-naphthol, but whether these compounds are true intermediates remains undecided.

54. Turner, E. R. (1955). The effect of certain adsorbents on the nodulation of clover plants. *Ann. Bot., N.S.* **19**. (In the press.)

The addition of charcoal to the rooting medium of clover plants inoculated with effective and ineffective strains of Rhizobium leads to a stimulation in nodule production. The time interval between inoculation and the first appearance of the nodules is reduced in the presence of charcoal. Several explanations of this phenomenon have been investigated, and it is concluded that the stimulation is due to the adsorption by the charcoal of inhibitory compounds secreted by the clover roots. These compounds have been eluted from the charcoal and have been shown to affect nodule production. As a result of these experiments it is suggested that, depending on the concentration of the secretions in the elutes either a stimulation or inhibition of nodule production may occur.

Other adsorbents have also been added to the clover plants, but no consistent stimulation of nodule production has been observed.

Botany Department

55. Owen, P. C. (1955). The respiration of tobacco leaves in the 20-hour period following inoculation with tobacco mosaic virus. *Ann. appl. Biol.* **43**, 114.

The effect of infection with TMV on the respiration of detached tobacco leaves in the 20 hours immediately after inoculation differed at different times of year. During winter, infection increased respiration rate, and in summer decreased it. In winter-grown plants, increasing the light intensity before inoculation decreased respiration rate after infection. Extending the day length for winter-grown plants did not alter the effect of infection. Changes in respiration rate began in less than one hour after inoculation and are, therefore, unlikely to be associated with the formation of new virus.

56. Owen, P. C. (1955). The respiration of tobacco leaves after systemic infection with tobacco mosaic virus. *Ann. appl. Biol.* **43**. (In the press.)

The rate of CO_2 production per g. dry matter of the younger leaves of tobacco plants systemically infected with TMV was about 10 per cent less than that of comparable healthy leaves. Older infected leaves had the same respiration rate as comparable healthy leaves. These results were independent of seasonal change in light conditions during the growth of the plants. Older leaves, but not younger leaves, of infected plants had a lower initial water content, and both absorbed less water during the experimental period than leaves from healthy plants. The effects of TMV infection on water content were so great that the rate of CO_2 production per g. fresh weight was sometimes significantly increased by infection. Other causes for contradictory results are discussed.

57. Thorne, G. N. (1955). Interactions of nitrogen, phosphorus and potassium supplied in leaf sprays or in fertilizer added to the soil. *J. exp. Bot.* **6**, 20.

Sugar beet plants absorbed nitrogen, phosphorus and potassium from leaf sprays supplying the three nutrients separately or in all combinations. Absorption of any one of the nutrients from a spray containing more than one nutrient was unaffected by the presence of others in the spray, but spraying with nitrogen-containing solutions increased the absorption of phosphorus and potassium from the soil, and potassium in sprays increased the uptake of phosphorus from the soil.

Nitrogen fertilizer applied to the soil increased leaf area, and hence it also increased the quantity of nitrogen, phosphorus and potassium deposited on the leaves from sprays and absorbed into the plants. Nitrogen fertilizer increased the apparent percentage recovery in the plant of phosphorus and potassium from leaf sprays. Phosphorus fertilizer had no effect on uptake from sprays, and potassium fertilizer appeared to reduce the percentage recovery of potassium from sprays. The significance of these percentage recovery figures is discussed.

Nutrients from sprays produced smaller increases in total dry weight and in dry weight per unit of nutrient absorbed than the same nutrient from fertilizer. Application of a nutrient in leaf spray reduced the response in dry weight and sugar yield to the same nutrient applied in fertilizer to the soil.

58. Thurston, J. M. (1954). A survey of wild oats (*Avena fatua* and *A. ludoviciana*) in England and Wales in 1951. *Ann. appl. Biol.* **41**, 619.

In 621 samples of wild oats, collected in England and Wales by National Agricultural Advisory Service and National Institute of Agricultural Botany Officers, only two species (*Avena fatua* and *A. ludoviciana*) were found, but both were very variable. *A. fatua* occurred in all wheat- and barley-growing areas, in both winter and spring corn and on all soil types. *A. ludoviciana* occurred (with two exceptions) only within approximately 80 miles radius of Oxford, mainly on heavy soils and chiefly in winter corn.

The amount of wild oats present appeared to depend on the frequency in the rotation of corn or other crops in which wild oats would shed seed. Deep ploughing often increased the infestation. The data did not show whether a field could be freed of wild oats by grassing down for a number of years, nor what is the maximum period of survival of buried wild oat seeds.

59. Warington, K. (1954). Trace elements. *Thorpe's Dictionary of applied chemistry*, **11**. London : Longmans, Green.

60. Wilson, J. H. (1955). Effects of nutrition and light intensity on symptoms of leaf roll virus infection in the potato plant. *Ann. appl. Biol.* **43**. (In the press.)

Increased nitrogen supply to potato plants infected with leaf roll virus greatly reduced the intensity of leaf symptoms, and caused a smaller and less consistent reduction in phloem necrosis. Application of phosphatic fertilizer initially reduced leaf symptoms, but later increased them; it increased phloem necrosis at all stages of growth. Potash slightly intensified leaf symptoms, but not phloem necrosis. Shading, which approximately halved the light intensity, reduced leaf symptoms but had no effect on phloem necrosis.

The masking of leaf symptoms by nitrogen, and by phosphorus in the early stages of growth, was closely correlated with increases in relative leaf growth rate produced by these nutrients.

Leaf rolling and phloem necrosis are considered to be independent symptoms not causally related, because they were differentially affected by nutrient supply and shading, and each could occur without the other.

Biochemistry Department

Books

61. Tracey, M. V. (1954). *Principles of biochemistry : A biological approach.* London : Sir Isaac Pitman & Sons Ltd.

62. Tracey, M. V. (1955). *Modern methods of plant analysis.* Edited by K. Paech & M. V. Tracey. Vol. 2. Berlin : Springer-Verlag.

General Papers

63. Kenten, R. H. (1955). Gasometric analysis in plant investigation. *Modern methods of plant analysis*, edited by K. Paech & M. V. Tracey. Berlin : Springer-Verlag. Vol. 1. (In the press.)

64. Pirie, N. W. (1954). On making and recognizing life. *New Biol.* **16**, p. 41.

65. Pirie, N. W. (1954). Factors controlling biological multiplication. *Nature, Lond.* **174**, 815.

66. Pirie, N. W. (1954). Food and the future. *Laden Wain, Reading*, p. 12.

67. Pirie, N. W. (1954). Food or frivolities. *Sci. Wkr*, **9**, 8.

68. Pirie, N. W. (1955). General methods for separation. *Modern methods of plant analysis*, Vol. 1, p. 26.

69. Pirie, N. W. (1955). Proteins. *Modern methods of plant analysis*, Vol. 4, p. 23.

70. Tracey, M. V. (1955). Chitin. *Modern methods of plant analysis*, Vol. 2, p. 264.

Research Papers

71. Holden, M. & Pirie, N. W. (1955). The partial purification of leaf ribonuclease. *Biochem. J.* **60**, 39.

From pea seedlings ribonuclease preparations have been made which attack P-containing substrates other than ribonucleic acid so slowly as to make it unlikely that the enzyme has an unspecific action.

The enzyme differs from pancreatic ribonuclease in that it hydrolyses nucleic acid so completely that no acid precipitable " core " is left.

Less thoroughly fractionated preparations have been made from tobacco leaves, and some properties of the enzyme in other leaves are described.

72. Holden, M. &. Pirie, N. W. (1955). The preparation of ribonucleic acid from yeast, tobacco leaves and tobacco mosaic virus. *Biochem. J.* **60**, 46.

Most of the nucleic acid in suitably prepared extracts from yeast, tobacco leaf microsomes and TMV can be precipitated at pH 3–4 by NaCl. A small part of the nucleic acid in commercial products can also be precipitated.

Preparations of nucleic acid made from yeast in this way appear to have a high mean particle weight and to contain less than I per cent of nitrogen. Their contents of Ca, Fe and Mg are low, and probably the results of contamination. Those from TMV contain significant amounts of deoxyribose nucleic acid, but the other two are substantially free from it.

73. Holden, M. & Pirie, N. W. (1955). A comparison of leaf and pancreatic ribonuclease. *Biochem. J.* **60**, 53.

The effect of variation in the conditions on the completeness of the precipitation of yeast nucleic acid by uranyl nitrate and trichloroacetic acid is investigated.

Ribonuclease from pea leaves hydrolyses nucleic acid more extensively than the pancreatic enzyme. There are also differences in thermostability and pH optimum.

The leaf enzyme is the more easily affected by several inhibitors.

74. Holden, M. & Pirie, N. W. (1955). Treatments affecting the ultra-violet absorption spectrum of ribonucleic acid from three sources. *Biochim. biophys. Acta*, **16**, 317.

The intensity of absorption in the 260-mμ region by three different types of ribonucleic acid and by the fraction of YNA that resists attack by pancreatic ribonuclease, is increased during several types of hydrolysis to an extent that parallels the extent of hydrolysis.

Exposure to strong urea solutions has a small and irregular effect on the absorption by nucleic acid, but diminishes the absorption by TMV.

75. KENTEN, R. H. (1955). The oxidation of indolyl-3-acetic acid by waxpod bean root sap and peroxidase systems. *Biochem. J.* **59**, 110.

The oxidation of indolyl-3-acetic acid (IAA) by O_2 is catalysed by highly purified peroxidase preparations. The rate of oxidation is increased in the presence of certain thermostable factors such as monophenols, aniline, resorcinol, manganese, and maleic hydrazide. With the exception of manganese and maleic hydrazide, all the active factors are known, or have been shown, to be peroxidase substrates. Other peroxidase substrates, e.g., catechol, hydroquinone, pyrogallol and *p*-phenylenediamine (10^{-4}–$1^{-5}M$.) strongly inhibit the peroxidase-catalysed oxidation of IAA.

The IAA oxidase of waxpod bean root sap consists of a thermolabile fraction, which appears to be a peroxidase and which can be replaced by horseradish peroxidase, and a thermostable fraction, the activity of which largely depends on the presence of peroxidase substrates.

The oxidation of IAA when catalysed by horseradish peroxidase in the absence or presence or waxpod bean root thermostable fraction proceeds with the consumption of 1 mole O_2/mole IAA oxidized and the formation of 1 mole CO_2/mole O_2 consumed.

Possible mechanisms of the reaction are discussed, and evidence is presented suggesting that the oxidation of IAA by the peroxidase systems studied is not dependent on the presence of flavoprotein.

76. KENTEN, R. H. & MANN, P. J. G. (1954). A simple method for the preparation of horseradish peroxidase. *Biochem. J.* **57**, 347.

A simple method is described for the preparation of highly purified peroxidase from horseradish roots. Stable, dry preparations are obtained with P.Z. 1040–1120 and haemin contents of 1·1–1·2 per cent.

77. MANN, P. J. G. (1955). Purification and properties of the amine oxidase of pea seedlings. *Biochem. J.* **59**, 609.

A method is described by which the amine oxidase of pea seedling extracts can be purified up to 300-fold.

The purified enzyme preparations catalyse the oxidation not only of diamines but also, though less readily, that of phenylalkylamines, aliphatic monoamines and of L- and D-lysine.

Hydrogen peroxide is formed during the oxidation of all the substrates. The inactivation of the enzyme by hydrogen peroxide has been confirmed, and the conditions of this inactivation have been investigated.

The enzyme is inhibited not only by cyanide and semicarbazide, as previously reported, but also by diethyldithiocarbamate, salicylaldoxime and potassium ethyl xanthate. Salicylaldoxime and thiourea are oxidized by the hydrogen peroxide formed in the primary reaction. This oxidation of salicylaldoxime is catalysed by peroxidase.

It is suggested that one enzyme–plant amine oxidase—catalyses the oxidation of diamines, phenylalkylamines and of L- and D-lysine and that this enzyme may be a metalloprotein.

78. (CHIBNALL, A. C.) & WILTSHIRE, G. H. (1954). A study with isotopic nitrogen of protein metabolism in detached runner bean leaves. *New Phytol.* **53**, 38.

A cycle of protein breakdown and synthesis was demonstrated in leaves kept for 4 days in the dark. The α- and ε-amino-groups of lysine isolated from leaf protein were equally labelled with isotopic nitrogen.

TRECCANI, V., WALKER, N. & WILTSHIRE, G. H. (1954). The metabolism of naphthalene by soil bacteria. *J. gen. Microbiol.* **11**, 341.

For summary see no. 53.

Plant Pathology Department

General Papers

79. Bawden, F. C. (1954). Inhibitors and plant viruses. *Advanc. Virus Res.* **2**.

80. Bawden, F. C. (1954). Cellular metabolism and virus growth. *Int. Symp., The Dynamics of Virus and Rickettsial Infections, Detroit*, p. 59.

81. Bawden, F. C. (1954). The development of knowledge on plant viruses and virus diseases. *J. sci. industr. Res., Ser. A*, **13**, 106.

82. Bawden, F. C. (1954). The spread and control of plant virus diseases. *Ann. appl. Biol.* **42**, 140.

83. Bawden, F. C. (1954). Tom Goodey (1885–1953). *Obituary Notices of Fellows of the Royal Society*, **9**, 141.

84. Bawden, F. C. (1954). Combating plant diseases. *Financial Times*, 15 November.

85. Broadbent, L. (1954). Potato seed can be saved. *Fmrs' Wkly*, **40**, 79.

86. Glynne, Mary D. (1954). Causes of variation in wheat yields. *Rapp. Commun. Int. Bot. Congr.* Sect. 18–20, p. 134.

87. Glynne, Mary D. (1954). Soil-borne diseases of cereals. *J. R. agric. Soc.* **115**, 41.

88. Hull, R. (1954). Sugar beet yellows in Great Britain, 1953. *Plant Path.* **3**, 130.

89. Hull, R. (1954). Sugar Beet Yellows. Recent developments in control. *Brit. Sug. Beet Rev.* **22**, 113.

90. Hull, R. (1954). Control of Yellows in sugar beet seed crops in Great Britain. *Agriculture, Lond.* **61**, 205.

91. Hull, R. (1954). The control of Virus Yellows in steckling beds. *Seed Tr. Rev.* **6**, 87.

Research Papers

92. Benda, G. T. A. (1955). Some effects of ultra-violet radiation on leaves of French bean (*Phaseolus vulgaris L.*). *Ann. appl. Biol.* **43**, 71.

Exposing the primary leaves of French bean to ultra-violet light produces a variety of effects, their magnitude depending on the extent of the exposure and the subsequent treatment of the leaves. Effects include some that are externally obvious, such as glazing and bronzing; others are detectable by changes in susceptibility to virus infection, by increased sensitivity to damage by ultra-violet and by an increased tendency for cells to collapse when the leaves are kept in darkness. Some of the effects can be counteracted by exposing leaves to visible light. Effects of radiation are not confined to epidermal cells, and measurements with detached epidermis indicate that from a quarter to a half of incident radiation of wavelength 2536 Å. may be transmitted by the epidermis.

The susceptibility of irradiated leaves to infection by a tobacco necrosis virus, as measured by the number of lesions produced by a given inoculum, depends on the irradiation dose, the time elapsing between irradiation and inoculation, and on whether the plants are in the light or dark after the treatments. When inoculated immediately after irradiation, leaves produce fewer lesions than unirradiated ones, even if they are kept in the light, but the

difference is much enhanced if they are in the dark. When leaves are inoculated a day after irradiation, provided the dose was not excessive, those kept in daylight after irradiation produce more lesions than unirradiated ones, whereas those kept in the dark produce many fewer. Thus, the temporary resistance produced by ultra-violet irradiation is not only counteracted by exposure to visible light, but is succeeded by a period of enhanced susceptibility, a period that extends over several days.

93. Cornford, C. E. (1954). Effect of downy mildew on yield of sugar beet. *Plant Path.* **3**, 82.

Field trials showed that sugar beets inoculated in June produced up to 80 per cent of infected plants, which decreased the yield of plots by nearly 2½ tons/acre of washed roots. Later inoculations caused less loss. When the weights of roots from individual plants of known history were compared, losses up to 37 per cent were measured in plants that developed symptoms in July.

94. Gates, L. F. & Hull, R. (1954). Experiments on black leg disease of sugar-beet seedlings. *Ann. appl. Biol.* **41**, 541.

Phoma betae was usually the predominant pathogen attacking sugar-beet seedlings in the field in eastern England, but *Pythium* species sometimes predominated when the seedlings were very young. *Fusarium* species were associated with acid soils. *Rhizoctonia solani* only occasionally caused severe losses.

Black leg, caused chiefly by *P. betae*, was most prevalent at low soil temperatures when, in stands from untreated seed, up to 45 per cent of the seedlings were attacked. Disease incidence decreased by 0·8–2·4 per cent per 1° F. rise in soil temperature. Seed treated with " Panogen ", thiram and ethyl mercury phosphate regularly gave better stands in small-scale trials than seed treated with " Ceresan " or " Agrosan ".

In large-scale experiments average increase in seedling emergence following treatment with " Panogen ", thiram and " Agrosan " varied in different years between +6·4 and +19·2 per cent. Average response to BHC soil dressing was +4·2 and +8·6 per cent. Response to seed dressings increased as the time taken for emergence increased and as percentage emergence decreased; when emergence was 50 per cent of the possible, dressing gave on average 20 per cent more seedlings. Response to dressing increased as soil became more acid or alkaline than the optimum for beet, and was lower on heavy soils and on soils dressed with farmyard manure.

Maximum emergence varied from year to year between 2,100 and 2,700 seedlings per ounce seed; minimum between 690 and 1,050. Emergence of both treated and untreated seed varied greatly, and was related to time taken for emergence, suggesting that effects of soil moisture, temperature or texture are important. Seed rate, cultural operations and drill type had no obvious effect. A 1 per cent increase in seedling stand increased final plant population on average by 0·2 per cent.

95. Gregory, P. H. (1954). The construction and use of a portable volumetric spore trap. *Trans. Brit. mycol. Soc.* **37**, 390.

For sampling air-borne spores a portable volumetric trap (which impacts spores down to 4 μ diameter on a stationary glass slide for microscopic examination) is operated manually by a light sliding-vane pump. Samples of 50–100 l. are taken in from 5 to 10 minutes. It is suitable for use when spore concentrations are high, and is particularly useful when an accurate time differentiation between samples is required.

96. Hamlyn, Brenda M. G. (1955). Aphid transmission of cauliflower mosaic. *Plant Path.* **4**. (In the press.)

Cauliflower mosaic has been considered as a non-persistent virus because it is acquired by *Myzus persicae* during 30 seconds' infection feeding, is transmitted during a few minutes' test feeding, and because aphids that are fasted before a short infection feed transmit more readily than do unfasted aphids. The response to preliminary fasting by *M. persicae* is smaller and less consistent than with other non-persistent viruses, and *Brevicoryne brassicae* gives little or no response. Aphids remain infective with cauliflower mosaic virus even after feeding for several hours on healthy plants.

97. HIRST, J. M. (1954). A method for recording the formation and persistence of water deposits on plant shoots. *Quart. J. R. met. Soc.* **80**, 227.

Apparatus has been designed to record the amount of water deposited on plant shoots by rain, dew and guttation, and how long the surfaces remain wet. These factors greatly influence the extent to which plants are infected by fungi causing such diseases as potato blight.

The water on a cut potato shoot, sealed into a water-filled chamber placed on a balance, can be weighed by recording, on a rotating drum, the changes in equilibrium of the beam. Deposits from rain appear rapidly; their persistence depends on the weather. In contrast, dew is deposited slowly over a long period, and dries more rapidly. The heaviest dew deposit recorded was $6{\cdot}9 \times 10^{-3}$ g./cm.^{2} compared with $9{\cdot}6 \times 10^{-3}$ g./cm.^{2} for the amount of water retained during rain.

98. HIRST, J. M. (1955). The early history of a potato blight epidemic. *Plant Path.* **4**. (In the press.)

Of 246 tubers infected with *Phytophthora infestans*, only two produced aerial shoots that were invaded by the fungus growing from the tuber. Plants near to the first of these developed blight lesions in late May, and the disease spread on at least five other occasions before it became widespread in the district at the end of July. Periods of spread usually coincided with potato-blight warnings by Beaumont's method.

99. KASSANIS, B. (1954). Heat-therapy of virus-infected plants. *Ann. appl. Biol.* **41**, 470.

Virus-free plants were produced from parents systemically infected with the following five viruses: tomato bushy stunt, carnation ring spot, cucumber mosaic, tomato aspermy and *Abutilon* variegation. The leaves formed while the infected plants were kept at 36° C. were free from symptoms, and test plants inoculated from these remained uninfected. When cuttings were taken from the infected plants at the end of the treatment most grew into healthy plants. The treated plants themselves usually developed symptoms after varying lengths of time at 20° C., but some that before treatment were infected with tomato aspermy, cucumber mosaic or *Abutilon* variegation viruses remained permanently healthy.

The same method failed to cure plants infected with tomato spotted wilt, potato virus X and tobacco mosaic virus, although it decreased their virus content. Heat-therapy seems not be correlated with the thermal inactivation end point of the virus *in vitro*.

100. KASSANIS, B. (1954). A virus latent in carnation and potato plants. *Nature, Lond.* **173**, 1097.

A virus detected by serology and electron microscopy in apparently healthy carnation plants is serologically related to a virus present in many normal-looking potato plants of several varieties.

101. KASSANIS, B. (1955). Some properties of four viruses isolated from carnation plants. *Ann. appl. Biol.* **42**, 103.

Four viruses isolated from commercial carnation varieties were transmitted to sweet william plants (*Dianthus barbatus* L.), which react characteristically with them. Two, carnation ring spot virus and carnation mottle virus, have spherical particles, the first about 19 mμ and the second about 32 mμ in diameter. Both survive heating for 10 minutes at 85° C. but not at 90° C. and remain active at room temperature in sap from sweet william for more than 2 weeks. They are not serologically related, and have not been transmitted by *Myzus persicae*.

The other two viruses are transmitted mechanically and by *M. persicae*. Carnation vein mottle virus inactivates in 10 minutes between 50° and 55° C. and at room temperature between 10 and 14 days; attempts to produce an antiserum against it failed; rod-like particles not seen in sap from healthy sweet william were occasionally seen in sap from infected plants. Carnation latent virus has rod-shaped particles. It produces no symptoms in carnation and sweet william plants; its presence is readily detected by serological tests. When transmitted by aphids to sugar beet, it sometimes causes the older

leaves to become yellow. Carnation latent virus inactivates in 10 minutes between 60° and 65° C. and at room temperature between 2 and 3 days. A virus serologically related to carnation latent virus occurs in apparently healthy potato plants of many different varieties.

102. Kleczkowski, A. (1954). Inactivation of antibodies by ultra-violet radiation. *Brit. J. exp. Path.* **35**, 402.

When sufficiently concentrated mixtures of different serum proteins are exposed to ultra-violet radiation, complexes, i.e., mixed aggregates composed of molecules of different proteins, are formed. Such complexes can also be formed between irradiated, but still active, antibodies and other serum proteins. The behaviour in flocculation tests of complexes formed between antibodies and an excess of serum albumin depends on the character of the antigen.

Inactivation of antibodies by ultra-violet radiation follows the course of a first-order reaction. The quantum yields for inactivation by the radiation of λ 2537 are *c.* $2{\cdot}4 \times 10^{-3}$ for the antibody to clover nodule bacteria and *c.* $0{\cdot}96 \times 10^{-3}$ for the antibodies to tomato bushy stunt and tobacco mosaic viruses.

Kleczkowska, J. & Kleczkowski, A. (1954). The effect of ribonuclease on phage-host interaction. *J. gen. Microbiol.* **11**, 451.

For summary see no. 42.

103. Last, F. T. (1954). The effect of time of application of nitrogenous fertilizer on powdery mildew of winter wheat. *Ann. appl. Biol.* **41**, 381.

Applying nitrogenous fertilizer (N) to wheat plants of different ages affected the incidence of powdery mildew, *Erysiphe graminis* DC, differently. When N was applied before the flag leaf had emerged, the infection-index (number of postules per 100 sq. cm. of leaf blade) increased to a maximum and then declined. If N was applied after the flag leaf had emerged, the infection-index increased steadily without reaching a peak, and the increased susceptibility was not associated with an increased relative growth rate as when N was applied earlier.

The integral of the number of pustules per unit area with time, and the number of perithecia on the leaves of the main stem, both increased with increasing delay in the application of N. Plants given N in either April or May had at least three times as many pustules as those given N in January. The time when N was applied did not affect the date when perithecia appeared.

After adding N to nitrogen-deficient plants, the already mature leaves which had resisted mildew infection became susceptible. This change is not associated with changes in the epidermal wall.

104. Last, F. T. (1955). The seasonal incidence of *Sporobolomyces roseus* Kl. et v.N. on cereal leaves. *Trans. Brit. mycol. Soc.* **38**. (In the press.)

The numbers of *Sporobolomyces roseus* Kl. et v.N. colonies developing on leaves of three crops (winter- and spring-sown wheat and spring-sown barley) were estimated by sampling at 14-day intervals, using a technique that selects fungi that grow on artificial media and whose spores are forcibly discharged.

After the internodes elongated and the crops became dense, the changes in numbers of *S. roseus* were similar in all three crops; leaves produced few colonies until they had lived half their lives, when the number of colonies progressively increased, to reach a maximum after the leaves died. Before the internodes elongated and the crop was still sparse, winter-sown wheat also produced colonies on still-living leaves, but in spring-sown wheat and barley colonies occurred in still-sparse crops only on dead leaves.

Dead leaves in summer had three times as many colonies per unit area as dead leaves in winter. The upper and lower surfaces of ageing leaves carried equal numbers of colonies, but the distal parts carried more than the proximal. The number of colonies seemed to be correlated with a high humidity that enables *S. roseus* to spread, and, perhaps, with exudations from ageing leaves of substances that encourage its growth.

The occurrence of *S. roseus* colonies seemed not to influence the develop-

ment of leaf parasites or to be influenced by them, but *Tilletiopsis minor* Nyland, another innocuous fungus that occurred only in July and August, greatly decreased the number of colonies, particularly on the spring-sown barley. In addition to these two species, *Cladosporium* spp. were regularly isolated from dead leaves, more abundantly during summer than winter, and *Bullera alba* (Hanna) Derx sporadically. It is suggested that, as with roots and the " rhizosphere ", leaves have a " phyllosphere ", with a characteristic micro-flora that may contain many species.

105. Last, F. T. (1955). Effect of powdery mildew on the yield of spring-sown barley. *Plant Path.* **4**, 22.

Spraying five times with lime sulphur did not affect the yield of the variety Haisa II, which resisted *Erysiphe graminis* DC, but much increased yields of the susceptible variety Plumage Archer. Mildew decreased the yield of Plumage Archer sown on 22 March by 13 per cent, on 5 April by 22 per cent.

106. Nixon, H. L. & Sampson, Joan (1954). A study of healthy and virus-infected plant cells by thin-section methods. *Proc. int. Conf. Electron Microscopy, London.* (In the press.)

Electron microscopy of very thin sections was used to study changes when tobacco-leaf parenchyma cells became infected with tobacco mosaic virus. The little change detectable in early stages of infection probably reflects the small proportion of cells invaded. The chloroplasts of infected cells show characteristic changes, the regular layered structure of the grana being replaced by granular vacuolate material. The size of the granules corresponds to that of cross-sectioned rods of the virus, and the cut surfaces, when shadowed, resemble the shadowed cut surfaces of intracellular inclusion bodies.

When chloroplasts extracted from infected leaves are digested with trypsin, rod-shaped virus particles are liberated in small amounts. The virus liberated by trypsin may correspond to the granular material filling the damaged chloroplasts.

Cooke, G. W. & Nixon, H. L. The value of sewage sludge ashes as phosphorus fertilizers. *J. Sci. Fd Agric.* (In the press.)

For summary see no. 27.

Nematology Department

General Papers

107. Doncaster, C. C. (1954). Nematology and eelworm pests in agriculture and horticulture. *Biology*, **20**, 17.

108. Peters, B. G. (1954). Control of plant nematodes. *Rep. Progr. appl. Chem.* **38**, 629.

Research Paper

109. (Lownsbery, B. F.) & Peters, B. G. (1954). The relation of the tobacco cyst nematode to tobacco growth. (Abstract of meeting.) *Phytopathology*, **44**, 497.

When tobacco plants were grown in pots of soil artificially infested with cysts of *Heterodera tabacum* at four densities from 50 to 3,200 larvae/g. of soil, it was found that heights at various dates and final weights of the plants were inversely proportional to log density. Thus, in normally fertilized plants, every ten-fold increase in density led to a weight loss of 139 g. The highest density to maintain itself at the end of the experiment was about 1,000 larvae/g. In a field experiment where the natural density had been reduced on some plots by prior injection of DD mixture, a broadly similar relation between height and log density was found, but here the DD led to such complicating effects as an increase in soil ammonia N at the expense of nitric N.

Insecticides and Fungicides Department

General Papers

110. Potter, C. (1953). The mechanism of action of insecticides. *3rd int. Congr. Phytopharm. Paris, 1952.* **1**, no. spéc.

111. Way, M. J. (1954). A problem of insecticides and biological control in East Africa. *Colston Pap.* **6**. (Proc. 6th Symp. Colston Research Soc., Bristol, 1953.)

Research Papers

112. Elliott, M. (1954). Allethrin. *J. Sci. Fd Agric.* **5**, 505.

Synthetic work leading to the commercial preparation of allethrin (the ester of (±)-*cis-trans*-3-*iso*butenyl-2 : 2-dimethyl*cyclo*propane-1-carboxylic acid [(±)-*cis-trans*-chrysanthemic acid] with (±)-2-allyl-3-methyl*cyclo*pent-2-en-4-ol-1-one [(±)-allethrolone]) is reviewed briefly. The relative insecticidal activity and abundance of the eight isomeric esters present in allethrin are deduced, and the most effective is shown to be (+)-allethronyl (+)-*trans*-chrysanthemate. The effect of various changes in the molecule of allethrin on insecticidal activity is described. The biological action of allethrin appears to be of a similar nature to that of the natural pyrethrins, and is associated with the particular stereochemical conformation in which the various parts of the molecule are held with respect to each other and with the chemical and physical properties of the groups so positioned. Although allethrin is inferior to the natural pyrethrins against most species of insects and by most methods of application, it is highly biologically active and, unlike many modern synthetic insecticides, has, so far, been found harmless to mammals.

113. Glynne Jones, G. D. & Connell, J. U. (1954). Studies of the toxicity to worker honeybees (*Apis mellifera* L.) of certain chemicals used in plant protection. *Ann. appl. Biol.* **41**, 271.

Laboratory techniques are described for the estimation of the stomach poison, direct and residual film contact poison and fumigant poison effects of chemicals to adult worker honeybees.

The toxicity of eleven chemicals used in plant protection has been investigated by these methods. The order of effectiveness as stomach and contact poisons was: parathion, TEPP, γ-BHC, dieldrin, aldrin, chlordane, *o, o*-diethyl-*o*-ethylmercaptoethyl thiophosphate (constituent of "Systox"), *bis*dimethylamino fluorophosphine oxide, toxaphene and the sodium salts of 2 : 4-D and MCPA : as residual films, dieldrin, aldrin, γ-BHC, parathion, chlordane and *o, o*-diethyl-*o*-ethylmercaptoethyl thiophosphate (constituent of "Systox"); toxaphene, TEPP and *bis*dimethylamino fluorophosphine oxide had no measurable effect; as fumigants, dieldrin, γ-BHC, aldrin, parathion and chlordane; the remainder had no measurable effect.

114. (Kalmus, H.), Kerridge, J. & Tattersfield, F. (1954). Occurrence of susceptibility to carbon dioxide in *Drosophila melanogaster* from different countries. *Nature, Lond.* **173**, 1101.

Until recently, all virus-induced susceptibility to carbon dioxide of *Drosophila melanogaster* seemed derived from one stock, and repeated search for another occurrence in many laboratory stocks remained unavailing. Some years ago, one of us (F. T.) discovered that *D. melanogaster* flies, recently trapped in the neighbourhood of Rothamsted Experimental Station, Harpenden, Herts., showed the characteristic hereditary carbon dioxide susceptibility, but as the other of us (H. K.) had kept at Rothamsted a few years earlier a substrain of L'Héritier's original stock, it was impossible to be sure that an escape was not responsible. However, a recent report has made it clear that carbon dioxide-susceptible flies, far from being rare, occurred in about one-third of all freshly trapped strains of *D. melanogaster* in France. In addition, we are indebted to a personal communication from Prof. L'Héritier, in which he states that he found susceptible flies in cultures from Israel but could not detect the susceptibility in flies from Africa or Japan.

In our own investigation, single flies trapped by ourselves, their offspring

or flies supplied by other institutions were bred in vials at 24° C. and tested about 1 week after emergence. *D. melanogaster* is often transported with fruit, and the place of trapping need not necessarily be the place of origin.

Our results show that carbon dioxide susceptibility occurs widely, but that flies from the same locality may sometimes be carbon dioxide-susceptible and sometimes carbon dioxide-resistant. The virus responsible for the susceptibility seems to be lost more or less quickly under laboratory conditions, which probably accounts for the fact that the susceptibility has not been rediscovered before.

The great differences among the resistant females from different strains in the rates of infection by susceptible males are probably due to some genetical and cytoplasmic properties of these strains, but it is at present difficult to correlate these with any environmental factor.

It should be mentioned that two trapped strains, which were shown by crossing to be *D. simulans*, were not susceptible.

115. KERR, R. W. (1954). Rearing *Drosophila melanogaster* Mg. for insecticide investigations. *Bull. ent. Res.* **45**, 313.

A method is described for rearing *Drosophila melanogaster* Mg., which provides a high and consistent yield of adult flies, of uniform age and size, for insecticide studies.

116. KERR, R. W. (1954). A method for the topical application of small measured doses of insecticide solutions to individual insects. *Bull. ent. Res.* **45**, 317.

A microburette made from glass capillary tubing is mounted on the mechanical stage of a microscope and filled with insecticide solution to a point at which the meniscus is in the field of the microscope. The magnified images of the meniscus and a calibrated micrometer scale in the eyepiece are projected on to a small screen mounted close to the tip of the microburette so that the scale and the insect being dosed can be seen simultaneously. This feature renders the apparatus particularly suitable for topical application work, in which accurate positioning of the dose on the insect is required. When an insect, held in a suction device described, is applied to the tip of the burette, the solution flows out unaided, and stops immediately the insect is removed. With the microburette described, doses from 0·005 to 0·035 μl. can be dispensed to within $\pm$0·00035 μl. The apparatus can be made to cover several other dosage ranges, either lower or higher, by simple modifications which are discussed.

117. KERR, R. W. (1954). Variation with age in the susceptibility to DDT and the respiration rate of male and female *Drosophila melanogaster* Mg. *Bull. ent. Res.* **45**, 323.

DDT in odourless distillate was topically applied to individual males and females of the Rothamsted wild type of *Drosophila melanogaster* Mg. The lines for the regression of mortality in probits on log dosage of DDT for males and females, 5 days old, were parallel, and males were 1·86 times as susceptible as females. Susceptibility was high in young flies, but rapidly decreased with age, to a minimum at about 5 days, thereafter increasing rapidly in males and not significantly in females. The need for sexing and standardizing age in flies used for toxicological investigation was thus demonstrated.

Respiration rate in untreated flies was measured by a modified Barcroft method. In males it increased with age up to 5 days, and then decreased; in females it increased with age up to 9 days. Variations with age in respiration rate and susceptibility to DDT were negatively correlated.

118. LORD, K. A. & POTTER, C. (1954). Organo-phosphorus insecticides. Insecticidal and anti-esterase activity of organophosphorus compounds. *Chem. & Ind.* p. 1214.

All available data indicate that esterases differ from one species of insect to another, and therefore it seems arbitrary to assume the ubiquitous occurrence of acetyl choline and enzymes which hydrolyse it. There is no doubt that in many species of insects acetyl choline hydrolysing enzymes occur and

that they are inhibited by organo-phosphorus insecticides, but there are other esterases which do not hydrolyse acetyl choline and are more readily inhibited by organo-phosphorus insecticides *in vitro*. These other enzymes may sometimes play an important part in the insecticidal action of organo phosphorus compounds.

119. Lord, K. A. & Potter, C. (1954). Differences in esterases from insect species : toxicity of organo-phosphorus compounds and *in vitro* anti-esterase activity. *J. Sci. Fd Agric.* **5**, 490.

Two types of esterase, the one capable of hydrolysing phenyl acetate and not acetyl-choline, the other able to hydrolyse acetylcholine, have been examined in adults of four species of insect—*Tenebrio molitor* L., *Tribolium castaneum* Hbst., *Dysdercus fasciatus* Sign. and *Blatella germanica* L.

The *in vitro* inhibition of both types of enzyme from each species has been examined with five organo-phosphorus compounds : tetra-ethyl pyrophosphate, paraoxon, parathion, OO-diethyl S-*p*-nitrophenyl phosphorothiolate and OS-diethyl O-*p*-nitrophenyl phosphorothiolate. Both types of esterase were inhibited by high dilutions of inhibitors. Susceptibility of both types of enzyme appeared to vary from species to species, and may provide a basis for specific differences in resistance to insecticides.

There is no consistent correlation between the toxicity of the compounds examined and the *in vitro* inhibition of either kind of esterase. Parathion did not inhibit any of the esterases. The other four substances were, in general, less potent inhibitors of the esterases that hydrolysed acetylcholine than those that did not. Therefore both types of esterase are worthy of further investigation, since there are insufficient data to decide which type of esterase is involved in the insecticidal action of organo-phosphorus compounds.

120. McIntosh, A. H. (1954). Temperature coefficients of insect kill by volatile solid insecticides. *Bull. ent. Res.* **45**, 137.

Three volatile solid insecticides (DFDT, γ-BHC and aldrin) were tested against two species (*Oryzaephilus surinamensis* and *Tribolium castaneum*) at two temperatures (30° and 11° C.) in simple laboratory fumigation tests. DFDT killed both species faster at 11° than 30° C.; γ-BHC killed *O. surinamensis* faster at 11° than 30° C., but *T. castaneum* faster at 30° than 11° C.; aldrin killed both species faster at 30° than 11° C.

121. Potter, C., Healy, M. J. & Feuell, A. J. (1954). A comparison of the chemical and biological assays of several strains of pyrethrum flowers. *Colon. Pl. Anim. Prod.* **4**, 59.

The collaborative experiment as a whole seems unsatisfactory because of the lack of clear-cut results, and because of some results which are conflicting.

Both the biological and chemical results show that the sample of C47 strain has marked disadvantages when compared with the samples of Mweiga and Cl strains.

The C47 sample appears more specific in action than the other two strains. While no major differences in toxicity appear with houseflies, it appears to be markedly inferior against some other species.

The rate of deterioration of flowers on storage is much greater with the C47 sample than with the other two, although a considerable amount of deterioration occurred with the Cl strain. There is some biological evidence to show that the deterioration is greater and certainly not less than the chemical figures indicate, and it seems that this strain may not easily be susceptible to the current methods of analysis.

It must be recognized that all these remarks apply only to the samples tested. The flowers from the so-called strains C1 and C47 are, in fact, taken from plants grown from the seed produced from crosses between two clones. These plants have a very large individual variation, and there is therefore a great liability to sampling error. Some figures are available for C47 which indicate that variations in the ratio of the pyrethrins do, in fact, occur with different samples.

However, the figures are enough to show that the C47 cross is not satisfactory as it stands, and that any strain that is subsequently developed should be carefully examined, both biologically and chemically, before going into production.

122. WAY, M. J. (1954). The effect of body weight on the resistance to insecticides of the last-instar larva of *Diataraxia oleracea* L., the tomato moth. *Ann. appl. Biol.* **41**, 77.

At a constant temperature of 24° C. the final larval instar of *Diataraxia oleracea* lasts about 10 days, during which its resistance to DDT and γ-BHC as contact insecticides progressively increases up to the 5th or 6th day. It then suddenly decreases, this coinciding with cessation of feeding and the beginning of prepupal formation.

Between the 2nd and the 6th days the gross body weight of the last-instar larva increases from about 0·27 to 0·65 g. Under the conditions of the experiments, the LD50 of parathion, as a stomach poison, was linearly related to body weight; on the same basis TEPP was slightly less, and lead arsenate, slightly more, toxic to the larger than to the smaller larvae. However, DDT as a stomach or contact insecticide, and γ-BHC as a stomach poison were notably less toxic to the larger larvae. For example, the increase in LD50 for an increase in larval body weight of ×2 was about ×11 for DDT as a stomach poison and about ×12 as a contact insecticide.

The order of effectiveness of the above insecticides as stomach poisons for the last-instar larva of *D. oleracea* was parathion >DDT>γ-BHC>TEPP = lead arsenate. Zinc fluoarsenate and rotenone were relatively non-toxic. Larvae of *D. oleracea* were repelled by food leaf treated with an extract of natural pyrethrins.

123. WAY, M. J. (1953). Studies on *Theraptus* sp. (Coreidae); the cause of the gumming disease of coconuts in East Africa. *Bull. ent. Res.* **44**, 657.

Theraptus sp. is widespread in the coastal region of British East Africa, where it severely damages developing coconut fruits.

The female may lay over 100 eggs. There are five nymphal instars and, in the field, it is probable that about nine generations are produced each year.

Damage to coconuts is similar to that caused by *Amblypelta cocophaga* China in the Solomon Islands. Female coconut flowers and young nuts may be destroyed by a single feeding puncture. Damaged 10–16-week-old nuts may reach maturity, but are undersized and often distorted by lesions from which gummy material exudes.

Over 70 per cent of 5–10-week-old nuts may fall "naturally"; thus *Theraptus* damages many nuts which would fall in any case. However, after natural nut-fall has ceased, the pest becomes concentrated on the few remaining nuts, which are susceptible to damage for about 4 weeks more. One *Theraptus* may make over 200 feeding punctures in its lifetime. Consequently, a population density of less than two per palm may cause severe damage.

Palms bearing many female flowers per spadix suffer more severely from attack than those bearing few, although normally they give higher nut yields.

124. WAY, M. J. (1953). The relationship between certain ant species with particular reference to biological control of the Coreid, *Theraptus* sp. *Bull. ent. Res.* **44**, 669.

In the coastal region of British East Africa three ant species, *Anoplolepis custodiens*, *A. longipes* and *Pheidole punctulata*, may destroy the ant *Oecophylla longinoda*, which is a valuable predator on the coconut pest *Theraptus* sp. (Coreidae). The three first-named species do not prey on *Theraptus*, which may severely damage palms occupied by them.

Nesting habits of the three ants species and their behaviour towards *O. longinoda* and certain other insects are described.

O. longinoda has been exterminated in the limited areas occupied by the two *Anoplolepis* species. *P. punctulata* is widespread, and is usually common in areas occupied by *O. longinoda*, and is also present, though relatively less common, in *A. longipes* areas.

The distribution of the *Anoplolepis* species, particularly *A. custodiens*, is correlated with sandy soils bearing a sparse ground vegetation. Where there are heavy soils or a thick ground vegetation of grasses and creepers the *Anoplolepis* species are absent and *O. longinoda* is usually present. It is suggested that the *Anoplolepis* species are limited by the relatively low temperature of soils shaded from sunlight by thick vegetation.

P. punctulata is not limited by thick ground vegetation, but, under these

conditions, *O. longinoda* is also abundant; probably adequate food is available in ground vegetation for *P. punctulata*, which thus does not compete for it with *O. longinoda* in the crown of coconut palms and other trees.

Cultural and chemical methods of controlling the harmful ant species are mentioned.

125. Way, M. J. (1954). Studies of the life history and ecology of the ant *Oecophylla longinoda* Latreille. *Bull. ent. Res.* **45**, 93.

In British East Africa *Oecophylla longinoda* (Latr.) var. *textor* Santschi is locally common in the coastal region. Inland it is absent from higher altitudes and from areas where there is a pronounced dry season.

In Zanzibar Island *O. longinoda* colonizes at least eighty-nine species of trees and shrubs; the largest populations occur on the clove (*Jambosa caryophyllus*), *Citrus* spp., *Bridelia micrantha* and *Canthium zanzibaricum*.

The nesting habits and colony composition of *O. longinoda* are such that one colony may spread over a number of adjacent trees; it contains only one gravid queen.

Winged virgin sexual forms are released at the beginning of the wet seasons, and new colonies are initiated by a single queen, who uses her food reserves to bring the first batch of brood to maturity.

In Zanzibar *O. longinoda* tends a wide range of Homoptera that produce honey-dew, but apparently " prefers " certain Coccids, notably *Saissetia* spp.

The degree of attention afforded by an ant species determines the species of Homoptera which it is able to attend.

The insect species preyed upon by *O. longinoda* include the honeybee, *Apis mellifera*, and the driver ant, *Dorylus nigricans*, of which large numbers may be destroyed.

O. longinoda is of undoubted value for controlling certain coconut pests, notably *Theraptus* sp. (Coreidae), and its efficiency in coconut plantations could probably be much enhanced.

126. Way, M. J. (1954). Studies on the association of the ant *Oecophylla longinoda* (Latr.) (Formicidæ) with the scale insect *Saissetia zanzibarensis* Williams (Coccidæ). *Bull. ent. Res.* **45**, 113.

A close association exists between the ant *Oecophylla longinoda* (Latr.) and the scale insect *Saissetia zanzibarensis* Williams.

Several factors cause the scale to be rare in the absence of the ant. Contamination by honey-dew and sooty moulds prevents increase of the *S. zanzibarensis* population above a relatively low level, while, in addition, insect parasites and probably predators virtually exterminate the scale. A fungal parasite may destroy honey-dew-contaminated *S. zanzibarensis* under humid conditions.

The attendant *O. longinoda* prevents contamination of the scale by honey-dew. It gives absolute protection from Coccinellid predators and, although parasitism by *Coccophagus* spp. and predation by *Eublemma* spp. is not prevented, the mortality of *S. zanzibarensis* which they cause is thought to be of little significance.

O. longinoda workers benefit *S. zanzibarensis* in other ways. They remove debris from the scale clusters; they transport the nymphs and establish them at suitable feeding sites. The effect of these benefits is most marked when the ant population is high relative to that of the scale.

The silken shelters built by *O. longinoda* over *S. zanzibarensis* clusters protect the ant during adverse weather, and may only incidentally benefit the scales.

S. zanzibarensis and other honey-dew-producing Homoptera are the major food source for *O. longinoda*. Other sources are sufficient to maintain only relatively low populations of the ant.

The level of the *S. zanzibarensis* population depends on the level of the attendant *O. longinoda* population. Scales providing honey-dew in excess of the requirements of an ant colony are killed.

The *O. longinoda* worker shows two distinct patterns of behaviour towards *S. zanzibarensis*. When it is not being attracted by the desire for honey-dew its behaviour resembles that adopted towards insects on which it normally preys.

127. WAY, M. J., SMITH, P. M. & POTTER, C. (1954). Studies on the bean aphid (*Aphis fabae* Scop.) and its control on field beans. *Ann. appl. Biol.* **41**, 117.

Field trials on chemical control of *Aphis fabae* Scop. attacking spring-sown field beans were carried out during the years 1950–52. The insecticide sprays were applied once only, soon after primary aphid migration into the bean crop had ceased. Destruction of the few aphids present at this early date stops build-up of the big populations that often develop later.

An 0·2 per cent (w/v) parathion spray was used in all three field trials. This gave excellent control of *A. fabae*, as did the systemic insecticides " Isopestox " and " Systox " at 0·05 per cent (w/v) active ingredient, and nicotine at 0·1 per cent (w/v). Sprays containing allethrin (0·05 per cent (w/v) pure material), pyrethrins (0·05 per cent and 0·02 per cent (w/v) total pyrethrins plus piperonyl butoxide) and an 0·1 (w/v) DDT emulsion gave moderate control. *A. fabae* was not controlled in plots treated with an 0·1 per cent (w/v) DDT crystalline suspension, and the aphid population reached a higher peak than in the untreated plots; the suspension is not only relatively ineffective against the aphid, bus is more toxic than the DDT emulsion to its Coccinellid predators.

On the bean plant the 0·05 per cent (w/v) " Systox " spray showed some residual toxicity to *A. fabae* for at least 5 days after application, but stopped causing 100 per cent kill within 24 hours. 0·02 per cent (w/v) parathion and 0·1 (w/v) DDT emulsion had slight, and 0·02 per cent (w/v) pyrethrins and 0·1 per cent (v/v) nicotine, no residual toxicity.

In the year 1950 aphid attack on the field plots was slight and damage insignificant. In 1951 there was a moderate attack, and the yield of bean seed was significantly increased by all insecticidal treatments; where aphid control was most efficient (parathion and " Isopestox " treatments) the yield (16·7–17·1 cwt./acre) was about ×2·7 that of the untreated control (6·3 cwt./acre). In 1952 there was severe aphid attack, and the mean seed yield of the untreated control plots was 1·4 cwt./acre. Plots treated with the DDT suspension yielded 1·3 cwt. seed/acre, but all other insecticides, including the DDT emulsion, increased the seed yield to 10·3–14·8 cwt./acre.

All preparations used in 1952, except nicotine, were destructive to adult Coccinellid predators of *A. fabæ*; *Adalia bipunctata* was more susceptible than *Coccinella septempunctaa*. However, in 1952 predators on the experimental area were too uncommon to be economically important.

Entomology Department

128. BANKS, C. J. (1954). A method for estimating populations and counting large numbers of *Aphis fabae* Scop. *Bull. ent. Res.* **45** (4), 751.

128a. BANKS, C. J. (1954). Random and non-random distributions of Coccinellidae. *J. Soc. Brit. Ent.* **4** (9), 211.

129. BARNES, H. F. (1953). Investigations into the gall midges of Chrysanthemum flowers. *Entomologist*, **86**, 292.

Of the seven gall midges that live in the flowers of wild Ox-eye Daisy (*Chrysanthemum leucanthemum*), four are primary and may do damage, one lives as an inquiline, one is predaceous on the larvae of other gall midges and one is predaceous on aphids that occur in the flowers. One of the primary species has already become a pest on cultivated chrysanthemums (Esther Read variety of *C. maximum*) and can breed also on *C. carinatum* and *C. frutescens*. Another primary species can develop on Esther Read, but has not yet been recorded on commercial crops. A provisional host-plant range list of all these gall midges is given.

130. BARNES, H. F. (1954). The study of gall midges at Rothamsted. *Marcellia*, **30**, Suppl., p. 15.

An account of how far the aims and objects of the gall-midge section of the Entomology Department have been accomplished, in building up an international collection and library while carrying out long- and short-term biological researches, particularly on fluctuations in numbers and host-plant range, as well as providing facilities for training other workers.

131. Barnes, H. F. (1954). Gall midge larvae as endoparasites, including the description of a new species parasitizing aphids in Trinidad, B.W.I. *Bull. ent. Res.* **45**, 769.

A review of the available information indicating the present locations of the type and other material. *Pseudendaphis maculans* gen. et sp. n. is described as an internal parasite of aphids, especially *Toxoptera aurantii* Boyer.

132. Barnes, H. F. (1954). Gall midges living in White Clover flowers. *Entomologist*, **87**, 258.

Preliminary information on the biology and distribution in England and Wales of *Brachyneura* sp., *Dasyneura* sp., *Lestodiplosis* sp. and *Clinodiplosis* sp. in White Clover flowers, as well as of *Dasyneura* sp., *Lestodiplosis* sp., *Clinodiplosis* sp. and *Hadrobremia* sp. in Red Clover flowers. The White Clover *Dasyneura* will intermate with a Red Clover *Dasyneura* and will breed in Red Clover flowers.

133. Barnes, H. F. (1954). A new species of *Trotteria* Kieffer (Cecidomyidae) reared from unopened flower-buds of Privet (*Ligustrum vulgare* L.). *Ent. Rec.* **66** (12), 281.

The description of *Trotteria ligustri* sp. n. from Norfolk, with a discussion of the possible larval feeding habits of the known *Trotteria* species.

134. Barnes, H. F. (1954). The Sorghum Midge problem. *Rep. 6th Comm. ent. Conf.* p. 101.

An exposition of the importance of gall midges, especially the Sorghum Midge, in the production of Sorghum throughout the world.

135. Barnes, H. F. (1954). Memorandum on the gall midges living on the Sorghums, The Panicum Millets and Rice. *Rep. 6th Comm. ent. Conf.*, Appendix B, 155.

The available information, published and previously unpublished.

136. Barnes, H. F. & Nayar, K. K. (1954). The Black Medick or "Trefoil" Gall Midge. *Plant Path.* **3** (2), 51.

Dasyneura lupulinae Kieffer has three generations a year on *Medicago lupulina*. It has not been possible to make it breed on Lucerne (*Medicago sativa*).

137. Barnes, H. F. & (Nijveldt, W.) (1954). A new gall midge, *Coccomyza leefmansi* sp. n., predaceous on the eggs of *Pulvinaria polygonata* in Indonesia. *Ent. Ber.* **15**, 91.

138. Dobson, R. M. (1954). A new species of *Carpophilus* Stephens (Col., Nitidulidae) found on stored produce. *Ent. mon. Mag.* **90**, 299.

Carpophilus halli, a new species found on stored produce, is described. The aedeagus of the male is figured, and a table enabling the new species to be distinguished from the closely related *C. dimidiatus* (F.) and *C. mutilatus* Er. is given.

139. Dobson, R. M. (1954). The species of *Carpophilus* Stephens (Col., Nitidulidae) associated with stored products. *Bull. ent. Res.* **45**, 389.

A key to most of the species of *Carpophilus* associated with stored produce is given, several species are redescribed, and new taxonomic characters are introduced and illustrated. Recent importations of the species into Britain are summarized.

140. Dobson, R. M. (1954). A note on the anatomy and morphology of the external genitalia of *Carpophilus obsoletus* Er. (Col., Nitidulidae). *Proc. R. ent. Soc. Lond.* (*A*), **29**, 45.

The external genital organs of both sexes of the species are described and figured, and the nomenclature of the various parts is discussed.

141. Haine, E. (1955). Aphid take-off in controlled conditions. *Nature, Lond.* (In the press.)

142. Johnson, B. (1954). Effect of flight on behaviour of *Aphis fabae* Scop. *Nature, Lond.* **173**, 831.

143. (C. E. Taylor) & Johnson, C. G. (1954). Wind direction and the infestation of bean fields by *Aphis fabae* Scop. *Ann. appl. Biol.* **41**, 107.

Five out of six bean fields at Sutton Bonington showed a bias in intensity of infestation on the sides facing the wind during primary migration.

144. Johnson, C. G. & Taylor, L. R. (1955). The development of large suction traps for airborne insects. *Ann. appl. Biol.* **43**, 51.

The designs of traps for hoisting on a barrage balloon and of other large suction traps.

145. Johnson, C. G. & Taylor, L. R. (1955). The measurement of insect density in the air. *Lab. Pract.* (In the press.)

An account of the main problems of aerial density measurement, the use of suction traps to overcome them and the special difficulties in the design and operation of suction traps and tow-nets used on a barrage-balloon cable up to several thousand feet in the air.

146. Long, D. B. (1954). Factors affecting the larval spot colours of the Emperor Moth, *Saturnia pavonia* L. *Nature, Lond.* **174**, 563.

147. Raw, F. (1955). Observations on Wheat Bulb Fly infestation of Broadbalk wheat plots. *Plant Path.* **3** (4), 134.

Studies on a section of Broadbalk carrying its first crop after fallow suggested that the intensity of wheat bulb fly attack might be affected both by the amount of organic residue in the soil and by the density of wheat shoots when the eggs hatch. The need for further work is stressed.

148. Raw, F. (1955). The effect of soil conditions on Wheat Bulb Fly oviposition. *Plant Path.* (In the press.)

In a factorial experiment designed to investigate the effects of soil conditions on oviposition, more eggs were laid on plots having a rough tilth than on those having a smooth tilth. More eggs were also laid on plots which were cultivated regularly during the oviposition period. Manuring of the plots had no effect on oviposition.

149. Southwood, T. R. E. (1954). Some additions to the Hertfordshire list of Hemiptera–Heteroptera. *Ent. mon. Mag.* **90**, 35.

Notes on the capture within the grounds of Rothamsted of eight species new to Hertfordshire.

150. Southwood, T. R. E. (1954). The production of fertile eggs by *Cimex pipistrelli* Jenys (Hem., Cimicidae) when fed on human blood. *Ent. mon. Mag.* **90**, 35.

151. Southwood, T. R. E. (1954). Notes on some Hemiptera–Heteroptera collected near Flatford Mill Field Centre. *Ent. mon. Mag.* **90**, 81.

152. Southwood, T. R. E. & Scudder, G. G. E. (1955). Notes on the bionomics and immature stages of the Thistle Lace Bugs (*Tingis ampliata* H.-S. and *T. cardui* L.; Hem., Tingidae). *Trans. Soc. Brit. Ent.* (In the press.)

Field studies have shown that *Tingis cardui* is confined to the involucre or the region just below it and *T. ampliata* to the vegetative regions of the thistle plant; the exact distribution of the latter varies with each larval instar. The principal host of *T. cardui* in this country is *Cirsum lanceolatum* and that of

T. ampliata is *C. arvense*. An account is also given of the colonization of thistle plants in the spring and the population during oviposition as shown by a marking and recapture experiment, of a Mymarid egg parasite, of the immature stages and their structure and of the presence of surface wax in the adults. A key to the larvae and the maps of world distribution of both species are included.

153. (Leston, D., Pendergrast, J. G.) & Southwood, T. R. E. (1954). Classification of the terrestrial Heteroptera (Geocorisae). *Nature, Lond.* **174**, 91.

The division of the Geocorisae into two main groups, the Pentomomorpha and the Cimicomorpha, is proposed as a result of studies of male genitalia; wing venation, spermatheca, eggs, salivary glands and other structures.

154. (Leston, D.) & Southwood, T. R. E. (1954). The structure of the egg and egg-burster of *Sehirus bicolor* (L.) (Hem., Cydnidae). *Ent. mon. Mag.* **90**, 291.

155. Stokes, B. M. (1955). Host plants of Wheat Bulb Fly. *Plant Path.* (In the press.)

Experiments carried out with grasses and cereals showed that wheat bulb fly (*Leptohylemyia coarctata* Fall.) could develop from newly-hatched larvae to maturity on at least thirteen different plant species, of which eight were not previously suspected. Evidence was obtained that a number of other grasses may also be host plants.

156. Taylor, L. R. (1955) (with an appendix by W. S. Coleman). The standardization of air-flow in insect suction traps. *Ann. appl. Biol.* (In the press.)

The amount of air sampled and its possible variation in field conditions has been measured for all the six types of trap available in the department; estimates of insect density obtained in different times and places by the same or by different types of suction traps can, therefore, now be compared. This information is presented in tabular form with a brief analysis of fan and trap construction in relation to variability of air-flow.

157. Taylor, L. R. & (Kalmus, H.) (1954). Dawn and dusk flight of *Drosophila subobscura* Collin. *Nature, Lond.* **174**, 221.

The strictly bi-diurnal activity of *D. subobscura*, hitherto known only as a feeding reaction to bait, was shown by suction trapping to exist normally as a flight periodicity in a natural population. It was suggested that the periodicity reflected an optical adaptation to dim light.

158. Westmacott, M. H. & Williams, C. B. (1954). A migration of Lepidoptera and Diptera in Nepal. *Entomologist*, **87**, 232.

An account of a migration of four species of butterflies and two species of Diptera in Nepal in March 1953, with comments on other similar Indian records.

159. Williams, C. B. (1954). Some bioclimatic observations in the Egyptian Desert. *Proceedings of Institute of Biology Symposium on "Biology of Hot and Cold Deserts"*, pp. 18–27.

A summary of microclimatic observations made in the desert near Cairo in 1923–24, chiefly demonstrating the range of temperatures and humidities available within a short distance to an animal capable of movement.

160. Williams, C. B. (1954). Notes on a small collection of Sphingidae from Nigeria. *Niger. Fld*, **19** (4), 176.

A collection of sixty-five individuals belonging to nineteen different species was made in a light trap during April 1953. The species and relative frequency are discussed from the point of view of migration and of population balance.

161. Williams, C. B. (1954). Notes on some migrations of butterflies in West Africa. *Entomologist*, **87**, 203.

A brief account of observations on migrations, chiefly of *Libythea labdaca* Westw., seen during a visit in April 1953 or reported by local naturalists.

162. Williams, C. B. (1954). Phenology—the Study of the Seasons. Presidential Address to Section X of the British Association. *Advanc. Sci.* **11** (43), 267.

A discussion of the co-operation of amateur and professional naturalists chiefly as illustrated by work on the phenology of plants, birds and insects.

163. Williams, C. B., French, R. A. & Hosni, M. M. (1955). A second experiment in testing the efficiency of insect traps. *Bull. ent. Res.* (In the press.)

An account of a comparison of two types of light-traps and two types of illumination, in an experiment which enabled us to separate the effects of position, night, trap and light, and also the previous night's trapping, in different groups of insects.

Bee Department

General Papers

164. Bailey, L. (1954). Nosema disease. *Bee World*, **35**, 69.

165. Bailey, L. (1954). Bee poisoning. *Bee World*, **35**, 221.

166. Butler, C. G. (1954). The importance of "queen substance" in the life of a honeybee colony. *Bee World*, **35**, 169.

167. Butler, C. G. (1954). Some observations relating to queen introduction. *Rep. cent. Ass. Brit. Beekeep. Ass.*

168. Ribbands, C. R. (1953). New evidence concerning the "language" of honeybees. *Advanc. Sci., Lond.* **10**, 24.

169. Ribbands, C. R. (1955). The scent language of honeybees. *Discovery*, **16**, 22.

Research Papers

170. Bailey, L. (1954). The control of Nosema disease. *Bee World*, **35**, 111.

The results of final experiments on the effect of transferring colonies on to clean comb are given. The disease was eliminated when bees were transferred on to clean comb and were allowed to recover their brood and stores from the old comb before the latter was removed. Methods and results of sterilizing old comb with acetic acid and formalin are given.

171. Bailey, L. (1954). The filtration of particles by the proventriculi of various aculeate Hymenoptera. *Proc. Roy. ent. Soc.* **29**, 119.

The correlation between the anatomy of the proventriculi of various hymenoptera and their efficiency in filtering particles from liquid suspension in the crop is described. The physiological significance of this function is discussed.

172. Bailey, L. (1954). The respiratory currents in the tracheal system of the adult honeybee. *J. exp. Biol.* **31**, 589.

The inactive bee inhales and exhales via the first thoracic spiracle. In air containing a high concentration of CO_2 the propodeal spiracle becomes active and its opening movements are synchronous with abdominal pumping. Under these conditions there is a marked current of air through the thorax, entering via the first thoracic spiracle and leaving via the propodeal spiracle.

173. Butler, C. G. (1954). The method and importance of the recognition by a colony of Honeybees (*A. mellifera*) of the presence of its queen. *Trans. R. ent. Soc. Lond.* **105**, 11.

Data are given in support of the theory that bees normally obtain something from their queens which inhibits them from rearing further queens. The results of experiments and observations indicate that a small number of the worker bees of a colony obtain this " queen substance " by licking all parts of the body surface of their queen, and subsequently share it with the other members of their colony. An adequate supply of " queen substance " inhibits worker ovary development as well as the production of new queens. It is suggested that in ants, bees and termites the collection and distribution of " queen substance " is the most important single factor in the maintenance of colony cohesion.

174. Free, J. B. (1954). The behaviour of robber honeybees. *Behaviour* **7**, 233.

It is shown that the characteristic, hesitant, swaying flight of robber bees is an innate response to the sight of a congestion of bees, either of their own or from another colony, near the entrance of the hive they wish to enter. When the entrance of a hive is not crowded with bees, robbers will enter without hesitation, even when the hive contains a colony of bees. It is concluded that guard bees quickly recognize would-be robber bees by their characteristic flight behaviour, and subsequently confirm their identity by olfactory examination.

175. Ribbands, C. R. (1954). Nitrous oxide anaesthesia does not encourage reorientation of honeybees. *Bee World*, **35**, 91.

Fully controlled experiments showed that anaesthesia with either " ammonium nitrate fumes " or nitrous oxide had no effect on reorientation. After carbon dioxide anaesthesia *more* bees returned to their original home. All the foragers from a nucleus which is taken from and placed near to its parent colony are likely to return to the latter, whether they have been anaesthetized or not; a variable proportion of the nucleus will consist of non-foragers, who are likely to remain in it.

176. Ribbands, C. R. (1954). The defence of the honeybee community. *Proc. Roy. Soc., B.* **142**, 154.

Pairs of colonies of differently coloured bees were placed with their entrances only 2 inches apart, and many bees tried to join the wrong colony, as if it were their own. Strangers were recognized by their different scent, and their reception varied according to foraging conditions. During " nectar flows " there was no hostility, and the bees of both colonies mingled indiscriminately. In fairly good conditions there was no hostility, but partial separation was maintained through the discrimination shown by incoming foragers. In dearth conditions, when bees try to rob other colonies, all strangers were received with hostility; most were thrown out, and many were killed. In dearth conditions marked foragers from one of the two colonies were fed with sugar syrup, but they were nevertheless repelled when they tried to enter the hive of the unfed colony; on the other hand, unfed strangers were more readily admitted into the fed colony. Thus hostility to strangers increased when forage was scarce; the condition of the community whose hive was to be entered was important, but the carriage of food by the intruder was not. These results are discussed in relation to defence of the community against both robber bees and strange queens.

177. Simpson, J. (1954). Effects of some anaesthetics on honeybees : nitrous oxide, carbon dioxide, ammonium nitrate smoker fumes. *Bee World*, **35**, 149.

Worker honeybees were apparently unaffected by atmospheric oxygen concentrations between 7 and 100 per cent, and only became motionless when the oxygen concentration was less than 2 per cent. The effects of nitrous oxide–oxygen mixtures differed little, if at all, from those of nitrogen–oxygen mixtures. Bees were not visibly affected by carbon dioxide concentrations up to 10–15 per cent, but became motionless if the concentration exceeded 40–45 per cent.

Fumes produced by adding ammonium nitrate to the burning fuel in a beekeeper's smoker were found to contain hydrogen cyanide or cyanogen. Their effectiveness as an anaesthetic may be due to this or to some unidentified component, but not to nitrous oxide. All these anaesthetics caused foraging bees to stop collecting pollen and accelerated the retrogression of the pharyngeal glands of young bees. The conclusion is reached that these anaesthetics do not encourage reorientation to a new hive site.

Statistics Department

Research Papers

178. Church, B. M. (1955). Problems of sample allocation and estimation in an agricultural survey. *J. R. statist. Soc., B.* (In the press.)

A sampling method which has been used in fertilizer surveys in England and Wales is described. The relative efficiencies and biases of several methods of estimating average fertilizer dressings are determined from the results of eight surveys carried out in 1950. The unbiased method of estimation is found to be 65 per cent efficient relative to the unweighted mean of the field observations; this latter method is only slightly biased. An alternative method of estimation, eliminating any gross bias which might occur in the unweighted mean, has a relative efficiency of 90 per cent.

179. Church, B. M. & (Strickland, A. H.). (1954). Sampling cabbage aphid populations on Brussels sprouts. *Plant Path.* **3**, 76.

The limitations of visual methods of assessing cabbage aphid density in the field are discussed. The technique of " three-leaf sampling " is described. Results obtained by laboratory counting of such samples are presented and the sampling errors examined. The method is shown to be much more efficient than the counting of aphid populations on whole plants. Attention is drawn to the problem of how intensively to sample individual Brussels sprout fields if an estimate of average aphid density is required for a whole sprout-growing area or region.

180. Grundy, P. M., Healy, M. J. R. & Rees, D. H. (1954). Decision between two alternatives—how many experiments? *Biometrics*, **10**, 317.

When a new process is suggested for use in agriculture or technology it is usually necessary to carry out experiments to estimate the increase in output that would result if the new process replaced that in current use. If the cost of experimentation and the scale of potential application of the new process are known, one method of arriving at an optimum amount of experimentation is to minimize the total risk given by the sum of the cost of the experiment plus the expected loss due to wrong decisions. The main difficulty is that the last quantity depends on the true increase in output due to introducing the new treatment, which can only be estimated from the results of the experiments. The paper discusses the case where an initial experiment is carried out, and it is required to decide whether to accept or reject the new treatment at once or else to carry out further experimentation. In the latter case the optimum amount of further experimentation has also to be decided. A solution is provided by minimizing the risk after eliminating the unknown parameter by averaging over its fiducial distribution based on the evidence from the initial experiment. Means for applying the resulting decision rule in practice are provided, and its performance under various circumstances is discussed.

181. Grundy, P. M. (1955). A method of sampling with probability exactly proportional to size. *J. R. statist. Soc., B.* (In the press.)

A practical method of drawing sampling units with probabilities exactly proportional to size is described, in which both preliminary calculations and the addition of a large number of sizes are avoided.

182. Healy, M. J. R. (1955). Statistical techniques for inspection sampling. *Trop. Agriculture, Trin.* **32**, 10.

An expository article describing methods of fixing sample sizes in single, double and sequential sampling schemes.

183. (Booth, V. H., Coates, N. E., Cox, C. P., Thompson, S. Y.) & Healy, M. J. R. (1954). Stability of caroten from dried grass meal and synthetic vitamin D_3 in chick mash. *J. Sci. Fd Agric.* (In the press.)

184. (Edwards, D. A. W., Hammond, W. H.) & Healy, M. J. R. (1955). Design and accuracy of calipers for measuring subcutaneous tissue thickness. *Brit. J. Nutr.* (In the press.)

This paper describes a series of experiments carried out at the request of the Medical Research Council Committee on Growth and Form, aimed at improving and standardizing the design of calipers used for measuring skinfolds. These measurements are becoming widely used as an assessment of body fat in many branches of human biology. The results of the experiments led to the laying down of a set of requirements for skinfold caliper design to ensure the best possible consistency between repeated measurements of the same fold. A new design of caliper fulfilling these requirements was introduced, and gave results markedly superior to most types of caliper in current use. A second set of experiments is described, in which the characteristics of the new type of caliper were assessed.

(Potter, C.), Healy, M. J. R. & (Feuell, A. J.). (1954). A comparison of the chemical and biological assays of several strains of pyrethrum flowers. *Colon. Pl. Anim. Prod.* **4**, 59.

For summary see no. 121.

185. Leech, F. B., (Egdell, J. W., Heskin, P. & Thomas, S. B.). (1955). Methods of milk production : some results of a survey in four areas of England and Wales. *J. agric. Sci.* (In the press.)

Methods, buildings and equipment used for milk production in Caernarvonshire, Hertfordshire, Pembrokeshire and Wiltshire have been ascertained by a random sample survey carried out in 1948–49. The results showed marked differences between counties in practically every respect. These differences are set out in thirty-one tables of results. As there have been marked changes in equipment, methods and materials available since the date of the survey, its main value is as an historical record of conditions at about the time these changes began. A later report will deal with the relationship between conditions on the farm and the keeping quality of the milk produced.

186. (Sellers, H. C.) & Leech, F. B. (1955). Survey of losses associated with pregnancy and parturition in Yorkshire sheep. *J. agric. Sci.* (In the press.)

Data concerning a random sample of about 4 per cent of the flocks in Yorkshire were collected in the form of answers to a questionnaire. The information required was given by 98 per cent of the farmers in the sample.

The survey has shown the extent of losses associated with pregnancy and parturition in 1952–53 and the areas in which they were most severe; it has also given some indication of the factors that might be affecting losses of different kinds. In addition to this information, the survey has provided statistics concerning feeding and husbandry and the relative importance of different breed types in Yorkshire.

Westmacott, M. H. & Williams, C. B. (1954). A migration of Lepidoptera and Diptera in Nepal. *Entomologist*, **87**, 232.

For summary see no. 158.

Reviews

187. Healy, M. J. R. (1955). "Design and analysis of industrial experiments", by Owen L. Davies. *Sci. Progr.* (In the press.)

188. Healy, M. J. R. (1955). "Biometrika tables for statisticians", edited by E. S. Pearson and H. O. Hartley. *Sci. Progr.* (In the press.)

189. Healy, M. J. R. (1954). Third International Biometric Conference. *Nature, Lond.* **173**, 1027.

Reports

190. Boyd, D. A. (1954). Suggested experimental designs for co-operative research projects. Working Party on Mediterranean Pasture and Fodder Development. FAO/54/4/2023.

191. (Ellison, W.), Boyd, D. A. & Church, B. M. (1954). Survey of hill and livestock rearing farms. (Mimeographed Report to the Agricultural Research Council.)

192. (Blood, J. W.), Church, B. M. & Davis, M. E. (1954). The survey of fertilizer practice, Northamptonshire, 1950–51. (Ministry of Agriculture mimeographed report.)

193. Church, B. M., (Blenkinsop, A. *et al*). (1954). The survey of fertilizer practice, 1953. (Ministry of Agriculture mimeographed report.)

Woburn Experimental Station

194. Mann, H. H. (1955). Variation of sulphur in soils under a continuous grain crop. *J. Soil Sci.* **6**. (In the press.)

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Rothamsted Park
Manor House
Public Footpaths.
All other footpaths private.
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